Studies of the Physical and Economic Effects of Flooding in an Agricultural Area in South West Scotland

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PREFACE

This Thesis is presented in fulfilment of the requirements of the degree of Doctor of Philosophy of the University of Edinburgh.

The work reported in this Thesis was undertaken in the United Kingdom during the three year period from October 1969 to September 1972. I certify that the work reported in this Thesis is the result of my own original research.

ACKNOWLEDGEMENTS

It is not possible to list here every individual who gave of their time and expertise to help me with this research. I thank all of these individuals now. The help of the following people and organisations, however, has been of particular value to me.

I must acknowledge the cooperation and patience extended to me by all of the farmers in the Nith area - in particular Mr. Gibb of Auchencrieff Farm and Mr. Slaven of Foregirth Farm - and by the farmers whose lands were inundated by the floods of the North East of Scotland in 1970. This cooperation would have been more difficult to achieve had it not been for the introductions provided for me by members of the Agricultural Advisory Service and the National Farmers Union to whom I am indebted.

Hydrological and economic data were kindly provided by the Department of Agriculture and Fisheries for Scotland and by the Solway River Purification Board. I am grateful to Mr. Truckle, Curator of Dumfries Museum, to the staff of the National Library of Scotland and to the local authorities at Dumfries for their help in tracing archive material. Considerable aid was offered to me by the Economics Departments of all three Scottish Agricultural Colleges - in particular the West of Scotland College - and by many insurance companies in particular the Edinburgh Insurance Brokers Company. I am grateful to all of these organisations.

I must extend my thanks to Professor J.W. Birch, Dr. K. Atkinson and Mr. J. Petch for reading parts of the manuscript and to Dr. D.C. Ledger both for reading and offering advice on the entire manuscript and for his help in the field.

Thanks are due to G. Bryant, T. Hadwin and R. Peacock for aid in preparing the diagrams and typescript.

Finally, I would like to thank my wife for her help and encouragement throughout the period of this research.

Leeds 29th October, 1974.

<u>SUMMARY</u>

A detailed examination of one protection scheme indicates that information on changes in flood frequency, extent and loss is lacking. In any "with and without" study of a protection scheme, one set of floods must be hypothetical. This study finds that direct questionnaire survey is an ineffective method of defining the attributes of the actual flood series. Physically based models which treat the floodplain as a storage area are found to identify flood extent with over 90 percent accuracy. Flood frequency studies indicate that significant hazard remains after protection.

This study finds that changes in flood potential in the protected area differ significantly from those in a control area, but that this differential change is of little financial significance. An unusually high proportion of floodplain farmers are found to have multiple land holdings.

Assumptions of total damage are shown to be invalid. Depth, a variable commonly linked with the prediction of damage, is found to be only one of a number of damage producing variables. The evidence suggests that the relative importance of these damage producing variables changes in different crops. Factor analytic techniques suggest that there are two basic components in the flood damage process - an erosive component and a biological component.

Loss estimates are demonstrated to vary markedly according to the assumptions made. It is found that the benefits stemming from

crop loss reduction, increased for potential equipment damage (and accepting the land enhancement value estimates of DAFS), do not exceed the maintenance costs in any year thus yielding a benefit to cost ratio less than one. Insurance, although found to be effectively unavailable, is believed to offer a more efficient form of protection.

CONTENTS

CHAPTER I

Introduction

1.1 Introduction

In 1970 the Water Resources Council of the United States of America identified flooding and floodplain management as an issue of concern in the seventies. A significant amount of the work undertaken under the auspices of the International Hydrological Decade concerns various aspects of flooding. It is clear that flooding remains an important research area at least in so far as it is internationally recognised as such. During the time that this research was being conducted serious flooding occurred in many continents: the major floods in the lower valley of the Danube in 1970; the floods that afflicted China in 1971; the almost annual disasters that have visited the Indian subcontinent; the widespread inundations of the areas round the Black Hills of Dakota in 1972. All of these events serve to focus the importance of flooding especially in the mind of the public.

The research worker in the field of flooding and flood control is perhaps more interested in the impact of <u>all</u> floods as opposed to that smaller subset of the more major floods. This more comprehensive viewpoint is of special importance to those who are particularly interested in the economic aspects of flooding. With this in mind consider the question: how important is flooding in economic terms?

In small countries serious flood events can have repercussions on the entire economy. That of the Phillipines Republic, for instance, reached its nadir in 1972 when any real growth in that year was halted by devastating floods. Evidence exists that flooding can also affect world prices and international trade. Consider the floods of April and May 1973 in the Mississippi Valley. Seven agricultural states were declared disaster areas; some 4,000,000 hectares of the best agricultural land in the United States were inundated; several thousand people were made homeless and property damage was estimated at $200,000,000. The fears of shortfalls in supply together with the expected increase in world demand immediately forced up the prices of many crops including wheat, cotton and maize. At the end of the floods, soyabeans, America's largest export crop, had reached a new world price of $7.50 a bushel. To reduce the domestic price American exports of these crops were curtailed. Thus world trade also felt the effects of the floods on the Mississippi. This is not an isolated occurrence. Floods can affect world markets, especially where the production of a commodity is concentrated in a particular area. See, for example, the comments of Boulware (1968) and Collins (1970) in relation to jute and wheat crops respectively.

In the United Kingdom flooding has never reached the catastrophic levels mentioned above. Nevertheless, as one of the few remaining major natural physical hazards that threatens the people of Britain, flooding is a matter of some concern to the resource manager.

On a per capita basis, the mean annual flood loss in the United Kingdom is £0.1798[1]. This small figure does not reflect the spatial and temporal concentration of losses that typifies flooding, as was clearly demonstrated by Butler and Marsell (1972) from empirical data for 1939 to 1969 in Utah. Nor does it reflect the potential damage by inundation that threatens some major cities - for example, London. Although losses have been estimated for individual floods - for example, the £11,000,000 loss estimate for the 1960 floods around the Severn, prepared by Harding and Parker (1973), Porter's estimate of the national cost of flooding is the only annual loss figure available.

The vulnerability of a number of urban and rural communities to sudden, unpredictable and possibly catastrophic flooding has brought about a vociferous and growing demand for protection. In response to these demands a number of flood protection schemes have been initiated. In most cases these schemes are not only organised by central government but are paid for out of central funds. Payments that are sometimes made by floodplain users towards the cost of the protection schemes generally seem to be "token" payments which in no

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[1]This figure is derived from Porter's (1972) estimate of mean annual damage in the U.K. - £10,000,000 - assuming a population of 55.6 x 10^6 determined from the Central Statistical Office (1971) midyear estimate of 56.14 x 10^6 reduced by 0.5 x 10^6 as a result of census disparity.

way reflect the real cost of the project. The annual flood protection expenditure for the United Kingdom has been estimated to be £16,400,000 (Porter, 1972). However, the account headings from which Porter derived this estimate include both drainage and protection expenditure and Porter was unable to differentiate between these two sources.

In the light of this substantial protection expenditure publicly incurred in the United Kingdom, it is surprising to find that there is an almost complete lack of information concerning the physical and economic efficiency of these works. The basis of these inadequacies may be the lack of information concerning flood losses themselves. Porter (1972) and Lee (1972) have emphasised this lack of data, as has Harding (1972):

> "In Wales there is simply no systematically collected data available at all and in many areas no information of any kind is available apart from the odd newspaper report of damage."

The world literature supports the identification of this gap in research. Although the literature on flooding is extensive (see the review and bibliographic material contained in Tennessee Valley Authority, 1969; Harding, 1972; Porter, 1972; Meteorological Office, 1970; Cochran, 1972) it is clear that three points must be made concerning the distribution of the research work. Firstly, the vast majority of the research work concerns the United States and, therefore, due to the differences that exist between the United

States and the United Kingdom in terms of legislation, price structure, agricultural patterns and river structure, many of the conclusions drawn from this literature are not relevant to the British situation. Secondly, in all of the literature, but particularly in that referring to Britain, the majority of the work is concerned with the technical and hydrological aspects of flooding and its control rather than the economic impact. Thirdly, the literature indicates that studies of agricultural flooding are exceedingly infrequent, yet as early as 1939, White showed that for specific floods 50 to 60 percent of the loss is in the agricultural sector. Ford (1953), making a nationwide estimate of flood losses, stated that 66 percent of the losses were in the agricultural sector.

In view of these gaps in an important research area, this thesis seeks, by means of a case study, to throw light upon some of the problems inherent in any study of the economic and physical impact of flooding and protection in an agricultural area.

Some laboratory studies have been carried out into the flooding of crops - see for example the work of Crawford and Taylor (1969), McManmon and Crawford (1971), Heinrich (1970), Forsythe and Pinchina (1971) and Haveland and Buchanan (1972). The bulk of the work concerns the tolerance of the plants to anaerobic conditions - often restricted to the rooting environment. These laboratory studies fail to simulate the high velocity, debris laden floods that occur in the field and for this reason laboratory studies are rejected here, in favour of a case study approach. This is in agreement with Matson (1959) who states that:

> "flooding in nature is a dynamic thing - measurement of flood damage experimentally might give less accurate results."

Harding (1972) has demonstrated that due simply to time it is not possible for one research worker to repeat the investigations necessary to gain an understanding of the flood situation at a number of sites. In addition Harding argues that sites are individual:

> "(flood studies) ... need to be considered in the context of specific study localities with particular occupance patterns and problems."

1.2 Study Area Selection and Description

In any case study the selection of the site is of paramount importance. In this study the site had to comply with the following constraints:

(i) It must be subject to river floods.

(ii) It must be located in a river basin with adequate flood records.

(iii) It must sustain mixed agriculture.

(iv) It must be structurally protected against flooding.

(v) It must be accessible.

The need for repeated field excursions limited the choice of site, due to travel time, to an area north of the Lakes/Tyne axis. Furthermore, the constraints of mixed agriculture and structural protection works effectively restricted the choice to the lower reaches of the larger rivers where "good" agricultural land is available in sufficient quantities to have attracted protection in the past. Reference to the 1965 Surface Water Yearbook showed further limitations to site choice[1] in that some rivers are totally ungauged, e.g. Rivers Naver, Don, South Esk (Aberdeenshire) and Helmsdale and others have only a single disused gauge site, e.g. Rivers Shin, Ness and Beauly. From this complex of constraints two river systems emerged as feasible choices for the prime investigation site, both having a history of flooding and a number of gauges. These were the Spey (hydrometric area 8) having 10 gauge sites and the Nith (hydrometric area 79) having 5 gauge sites.

Preliminary investigations of these two sites indicated that the Nith was to be preferred for the following reasons. The River Spey is hydrologically more complex due to the influence of engineering works for water supply purposes. This is reflected in the quality of the gauging network on the Spey, where 8 out of 10 gauges measure runoff that has been affected by reservoirs, catchwater channels and the import and export of water (sometimes in unknown quantities). The 2 remaining gauges do not measure the main river.

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[1]The 1965 Surface Water Yearbook shows at a glance the majority of stations that have records in excess of five years in 1969/1970. Clearly some stations will have been abandoned in the interval.

The Nith in contrast is a smaller river of simpler basic hydrology, the runoff from which is less severely influenced by engineering works. Afton Reservoir, Ayr County Council's reservoir in the Nith headwaters, has gathering grounds of 8.50 km^2, 1.06 percent of the drainage area above Friars Carse. The location of the gauge at Friars Carse is almost ideal, being sited immediately upstream of a flood prone agricultural area which extends south to the outskirts of Dumfries. The Nith tributary streams, the Afton, Scar and Cluden are all gauged and the Nith itself is gauged again to the north of Friars Carse at Hall Bridge. For these reasons the Nith was chosen as the study site.

The Nith lies in the eastern district of South West Scotland. The main stem of the river runs from north to south, but in its upper reaches the flow is in an easterly direction. The catchment area above Friars Carse, 808 km^2, is dominated by hill sheep farming. In the valley floors of the upper reaches of the river, dairy farming predominates but in the lower reaches dairy farming gradually is replaced by arable farming.

In the past the Nith has been a river of considerable importance. The Statistical Account of Dumfriesshire in 1841 indicates that the port of Dumfries handled over 480 inward bound ships. However, by 1909 this had dropped to 9 ships and indeed today one can attach no commercial importance to the port.

The major settlements in the Nith valley, Cumnock, Kirkconnel, Sanquahar, Thornhill and Dumfries (Figure 1.1) have generally arisen in response to the attractive geology of the area. The existence of

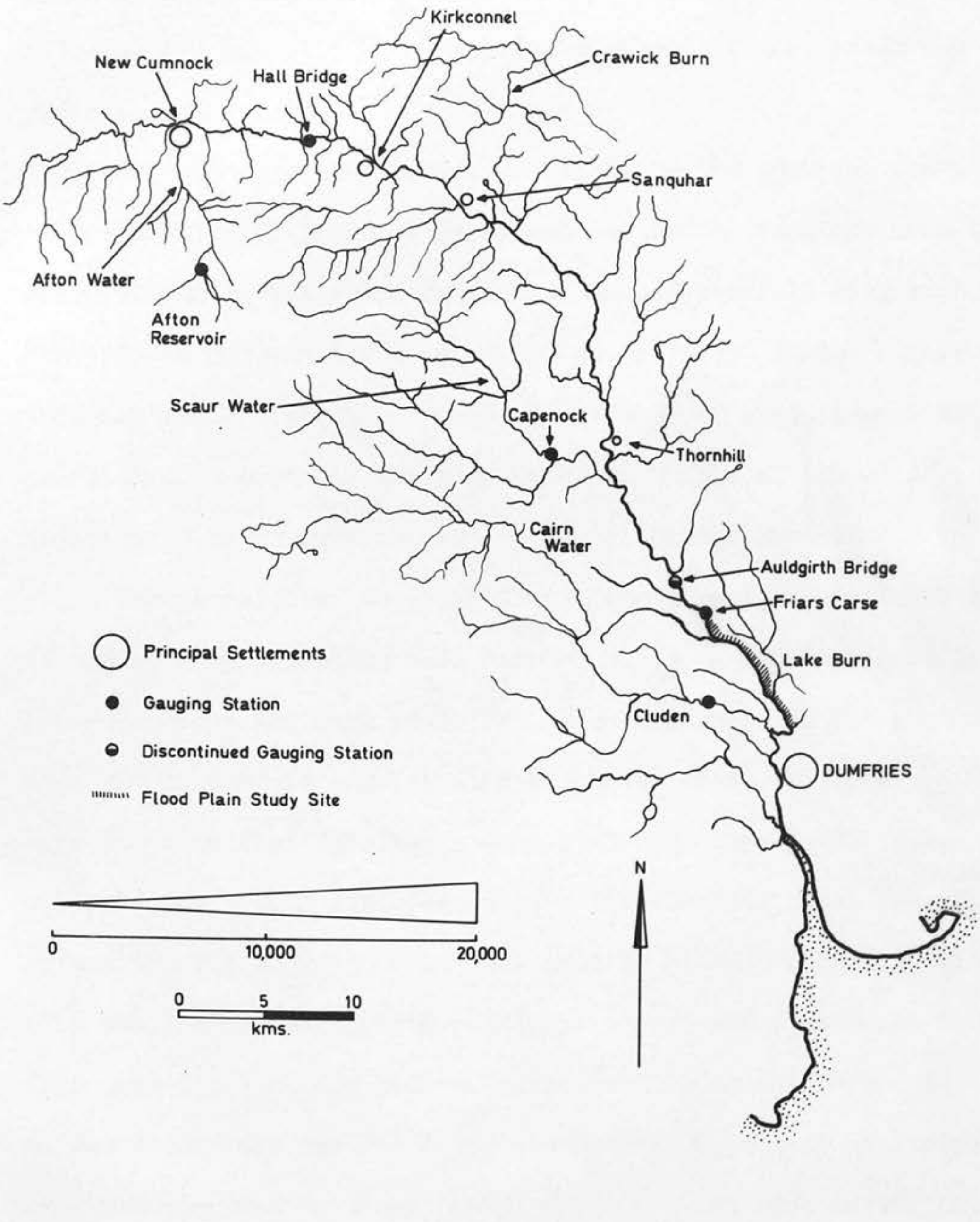

FIGURE 1.1 STUDY AREA AND LOCATION OF GAUGING STATIONS.

coal measures corresponds to the sites of all of these settlements. Today with the decline of the coal industry these communities have diversified to meet the employment needs of their populations. Forestry activities, both public and private, are now much in evidence and may well be an important source of employment and revenue in the future.

Climatically the area is dominated by the approach and passage of North Atlantic depressions except for those occasions when the flow follows an Icelandic pattern. Annual rainfall over much of the Nith is between 1,200 and 1,300 mm, although in the higher areas this may reach 2,500 mm. Only 60 to 70 mm of evapotranspiration is calculated to occur in the high rainfall months of the winter. The majority, over 85 percent, occurs in the summer months.

That section of the Nith floodplain in which detailed studies of agricultural flooding were carried out is shown in Figure 1.2. Field patterns and farm names are given because this information is extensively used in ensuing discussions of flood patterns. In this area the wide flat floodplain supports mixed arable with dairy agriculture. Well equipped, apparently thriving farms generally extend to over 40 hectares. The area is protected against flooding by a complex system of both publicly and privately financed levees. These are for the most part of faced earth bank design and the bulk of the system was installed in 1946 by the Department of Agriculture and Fisheries for Scotland (DAFS) who have been responsible for all subsequent maintenance. The levee encloses a wide floodway which theoretically should be clear of obstructions, although this is in

FIGURE 1.2 FIELD PATTERN AND FARM BUILDING LOCATION IN THE LOWER NITH FLOODPLAIN.

fact not the case. In parts the floodplain is covered by unbrashed woodlands designed for game cover. These woodland areas extend over the levee at some points and cover the floodway itself.

From Martington Bridge to Friars Carse the study area is some 10 km long. The bulk of the floodplain lies to the east of the channel and on average is 1 km wide. The floodplain loses on average some 12 m in height from 21 m O.D. in the north to 9 m O.D. in the south (these figures represent average field heights, <u>not</u> maximum and minimum spot heights in the floodplain). Changes in height in lines normal to the thalweg are usually in the region of 1 to 2 m. In parts of the southern area the ground slopes slightly away from the river.

This brief sketch of the floodplain and its agriculture, the levees which protect it and the catchment area which generates the flooding and contributes to the agricultural system of the floodplain will, it is hoped, serve to acquaint the reader with the study area. Appendix 1 gives a fuller description of the Nith catchment.

1.3 <u>Definitions</u>

In this thesis the term "flood" is used to refer to a river flood. If reference is made to insidious floods or to sea floods the fuller term will be used. The "hydrological", agricultural and damage aspects of sea floods have been studied by Wemelsfelder (1939), Van den Berg (1950) and Maris (1954) respectively. Insidious flooding occurs when rainfall rate exceeds infiltration rate or when the watertable or interflow reaches the ground surface. The laboratory studies mentioned above should be relevant to damage caused by this form of flooding.

Harding (1972) has examined four definitions of flooding, ranging from the hydrologist's to the resource manager's viewpoint. In short these are - any relatively high flow; any high flow that inundates normally dry land; any inundation that causes damage; and any inundation that causes or threatens to cause damage. Although the third definition is considered by Farrall and Albrecht (1965) to be that accepted by the farmer, for the purposes of this study the last definition is considered most appropriate. A flood as referred to in this thesis is a high flow that overtops the natural or artificial banks of a river and causes or threatens to cause damage.

1.4 Structure

In this initial Chapter the British and world importance of flooding has been emphasised. It has been noted that evidence from the few studies on hazard undertaken in the United Kingdom and from the literature indicates that there are major gaps in research in relation to flooding. These gaps concern the economic and hazard aspects of flooding, especially in relation to agriculture. A case study approach has been selected and the characteristics of the study site have been outlined.

In the following Chapter the flood history of the Nith and the data from which this history was derived are considered. A physically based model is developed to calculate the extent of the individual floods identified in the flood history. In the latter part of this Chapter the work concentrates on identifying the pattern and extent of the flooding that would have occurred without protection. The two patterns of flooding are compared.

In Chapter III the possibility that the differences in the flood patterns will have induced changes in flood damage potential is discussed. Previous attempts to identify changes in agricultural flood damage potential are considered and the methodology used in the Nith study is developed to take account of the apparent failures of other studies. The results of the work in the Nith and, where appropriate, the results of some parts of questionnaire surveys of Nith floodplain inhabitants are outlined and discussed.

In Chapter IV the work concentrates on the background problems associated with the evaluation of monetary loss. Terminological difficulties and deficiencies in the present assessment methodologies are analysed to determine the extent to which assumptions of total damage are justified. The relationships between damage and various aspects of the flood are examined.

In Chapter V the losses incurred in the Nith floodplain during the period of protection are calculated and compared with the estimated losses that would have occurred had protection not been available. In calculating these losses, 4 assessment strategies are compared. The benefits due to loss reduction are examined in the light of the protection expenditure. The insurance premium required to provide an alternative means of "protection" is calculated and the financial effects of changes in damage potential are investigated.

In the penultimate Chapter, it is argued that although the case study is now complete the results should be generalised with respect to time. Using historical and gauge data, a flood frequency analyis for the study area is presented. The losses suffered due to floods of various discharges and thus return intervals are computed under both protected and unprotected situations. The impact of flooding on agriculture and the efficiency of the protection works, as assessed through the frequency studies and through the flood history of the area, are compared. The effect of the use of other forms of flood frequency analysis on the apparent efficiency of the protection works is investigated.

The final Chapter draws conclusions and identifies, in the opinion of the author, the successes and failures of the research. Some future research needs as indicated by this work are outlined.

CHAPTER II

The Flood History of the River Nith and the Impact of Protection

2.1 Introduction

The object of this Chapter is to identify the changes in the frequency and extent of flooding that have occurred due to protection in the study area. The physical characteristics of two flood sets will be investigated. The first is that set of floods which occur despite protection. The second is that set of flood events which would have occurred if protection had not been available. To achieve this the Chapter falls into Sections dealing with the following:

(i) The flood history of the River Nith.

(ii) The preparation and testing of a physically based computer model to determine flood extent.

(iii) The determination of bankfull discharge in order (a) to identify the frequency of flooding without protection, and, (b) to aid the calculation of the overspill volume without protection as an input to a modified model derived from (ii) above.

(iv) A comparative examination of the frequency and extent of the floods in the two sets.

2.2.1 The Flood History of the River Nith

It is necessary to examine the flood history of the River Nith for the following reasons. Firstly, because it is necessary to identify the experienced frequency with which flooding has occurred. This is the inundation pattern that floodplain occupants have suffered and is therefore the basis on which they will make decisions concerning their reaction to hazard. Secondly, because it identifies for the research worker the available data base and thus identifies the data deficiences that must be made good.

The flood history has been studied in detail for the 25 year period for which the protection works have been in existence. A further 25 years have been examined in more general terms to expand the time covered to 50 years: the most commonly used period for project evaluation. Extending the record of all floods above a set base level beyond 50 years was not attempted due to the difficulty of using newspaper sources prior to 1900. Newspapers beyond this date have no contents or headline format. Severe flood events would be detailed on inside pages and thus a large expenditure of time would have to be made to gain relatively little return.

Three sources of data were examined in the establishment of the flood history of the River Nith. These were:

(i) River gauge data.

(ii) Newspaper reports and documentary evidence.

(iii) Wall markings.

2.2.1.1 River Gauge Data

The River Nith and its tributaries are gauged at five points: the Nith at Friars Carse and at Hall Bridge; the Afton Water at Afton

Reservoir; the Scar at Capenoch; and the Cluden at Fiddlers Ford. The gauge at Friars Carse which was established in 1957, has the longest period of record. In addition, it is located closest to the study area, being immediately upstream of the flood site. It is, therefore, the gauge of greatest interest to the present study.

The gauging station at Friars Carse consists of a continuous stage recorder installed and run until 1970 by the Department of Agriculture and Fisheries for Scotland (DAFS). Since then, it has been maintained and the records kept by the Solway River Purification Board. The station is sited on the east side of the Nith at Friars Carse (grid ref: NX 923851). At this point the river is narrow and the floodplain small in extent, being enclosed by the relatively steep slopes of the valley side. The river holds a straight course for several hundred metres above and below the gauge site. Control for the station is provided by the channel which is uniform for some 5 km below the site. The stage discharge curves used in the interpretation of the stage records during the time period relevant to this enquiry were prepared by DAFS. From the Friars Carse continuous record, it was possible to extract all of the high flows for the period from 1957 to 1969. The peak flows in each year for this period are shown in Figure 2.1.

The record of flow at Friars Carse is short and there is a need to supplement it to cover the length of time for which it is desirable to have flood information. Unfortunately records of previous flows are, with the exception of the wall markings mentioned below, not available

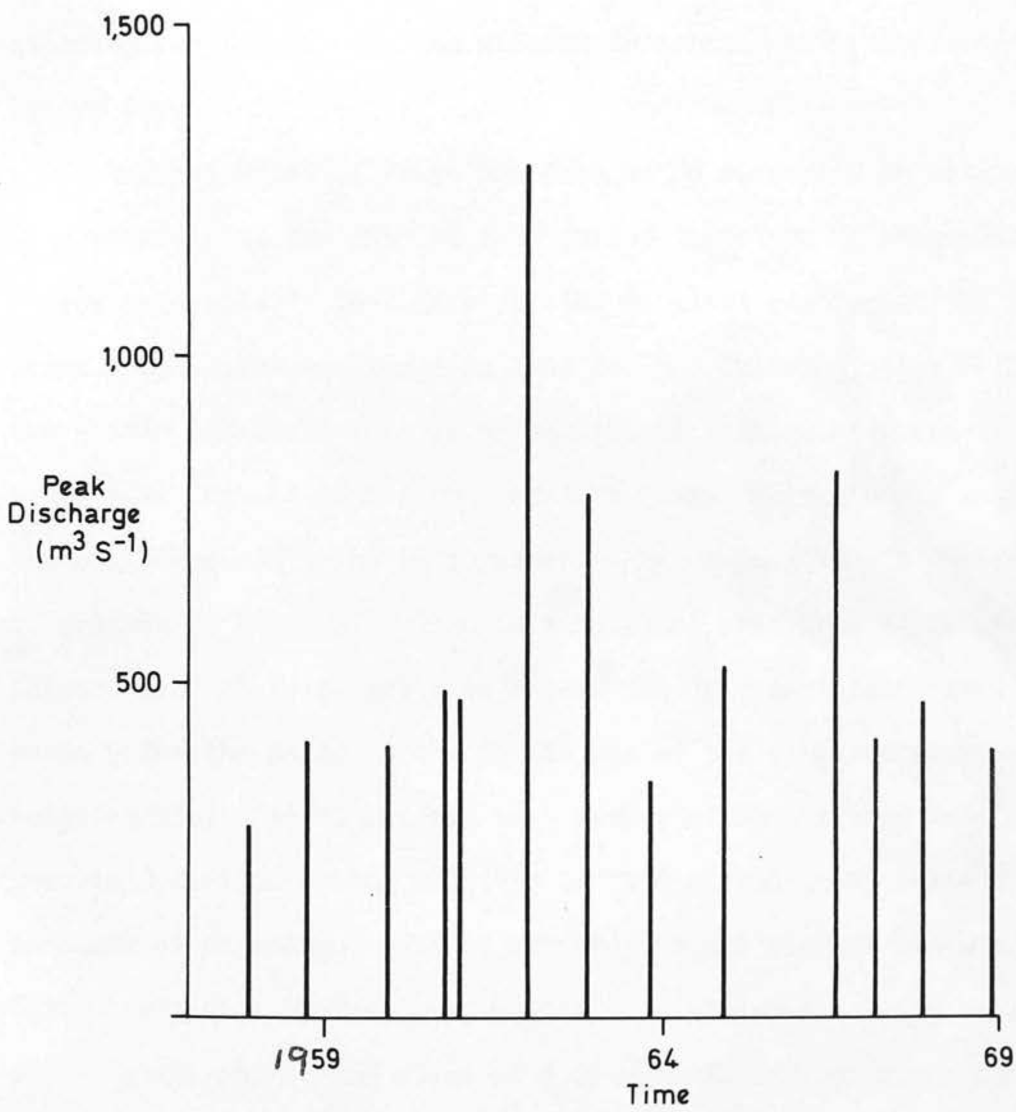

FIGURE 2.1 ANNUAL PEAK FLOWS AT FRIARS CARSE FOR THE PERIOD 1957 - 1969.

at Friars Carse. However, records of stage alone have been made for the period 1939 to 1956 at Auldgirth Bridge (grid ref: NX 912864) some 2 km river distance upstream of the present gauging site. The stage records at Auldgirth Bridge were reduced by correlation to stage records at Friars Carse. This was possible because the record at Auldgirth Bridge had been allowed to overlap with the record at Friars Carse for 1 year[1].

The estimates of stage now need to be converted to estimates of discharge. For the 1939 to 1956 period there are no stage-discharge curves available. In this study the earliest edition of the Friars Carse stage-discharge curve is used for the interpretation following the simple rationale that as no edition of rating curve can be proved best it is logical to use that edition linked most closely in time to the stage records to be interpreted. By examination of the full set of records of stage-discharge relationships available at Friars Carse (Figure 2.2) it is possible to assess the degree of inaccuracy that could enter the analysis due to the use of the earliest stage-discharge relationship. If it is assumed that either of the extreme relationships were in operation during the 1939 to 1956 period an 85 percent accurate estimate of discharge would be achieved at the highest stage of record, 5.18 m, whilst a minimum accuracy of over 90 percent would be attained at the still infrequent stage of 4.27 m. The random movements of the rating curves over time indicate that the implicit assumption that there

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[1]Credit for this record extension work lies with DAFS, to whom the author is grateful.

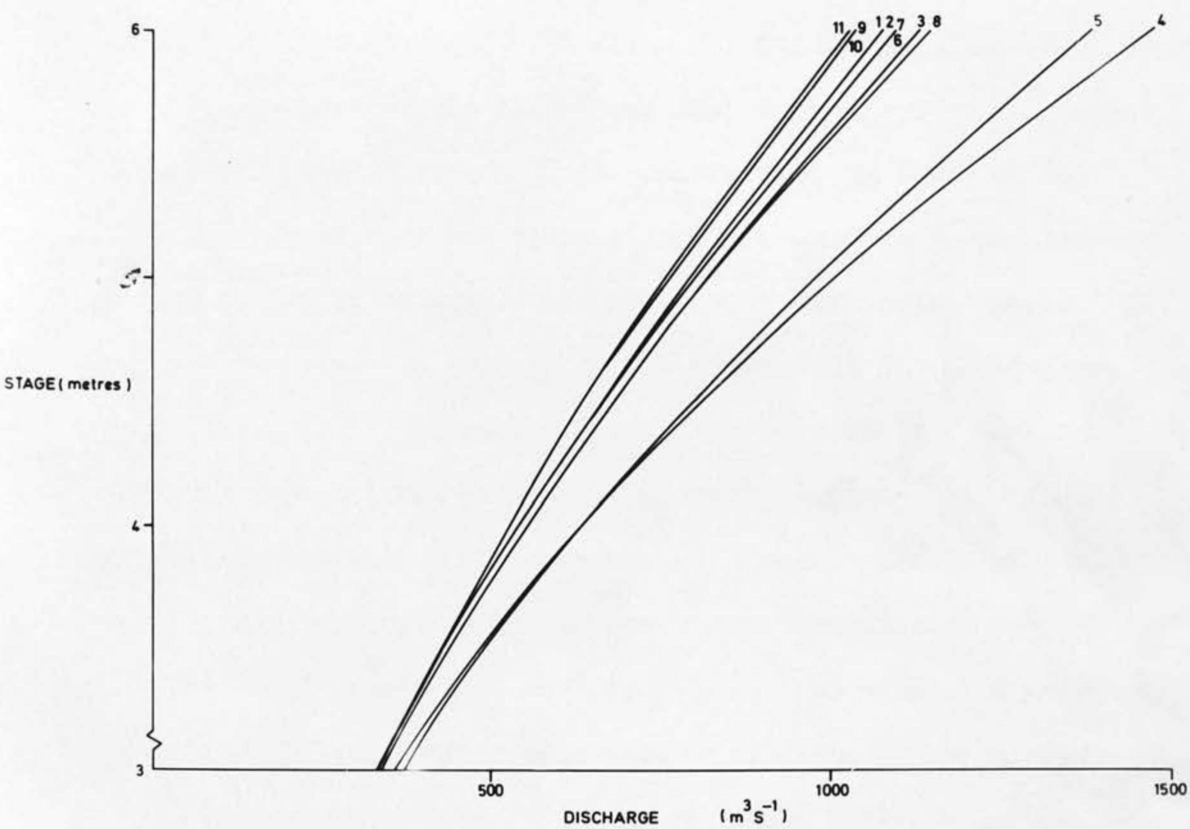

FIGURE 2.2 CHRONOLOGICAL ORDERING OF THE STAGE DISCHARGE RELATIONSHIPS AT FRIARS CARSE FOR THE PERIOD 1957 - 1969.

are no progressive changes in the slope of the rating curve is valid. Figure 2.3 shows the series of annual peak flows for the years 1939 to 1969 all expressed as discharge at Friars Carse.

2.2.1.2 Newspaper Reports and Documentary Evidence

Evidence from documents and newspapers has been used to extend the record prior to 1939. In doing so, the emphasis has been clearly put upon a subset of the high flows that were of sufficient impact to justify their inclusion in the documents. In terms of the efficient use of research time, it was not possible to examine each edition of two twice-weekly newspapers over the last 50 years. It was thus necessary to prepare a list of possible flood dates from cumulative, usually annual, indexed sources. To this end, an examination of British Rainfall, the County Almanac, and records of the Nith Navigational Commission and the Town and Country Roads and Planning Departments was carried out. The list of over 100 possible flood events went back to 1910 and was used as a reference guide to the diaries of amateur weather watchers and to editions of the two local newspapers used in the search: The Dumfries and Galloway Gazette and The Standard, from which a history of the times of actual floods was compiled. The question arises as to how the relative magnitudes or preferably the absolute magnitudes of these floods are to be determined.

It was possible to make estimates of the relative magnitudes of the floods using statements in the newspapers of the form: biggest for n years and greater than the 19nn flood. This was carried out as a

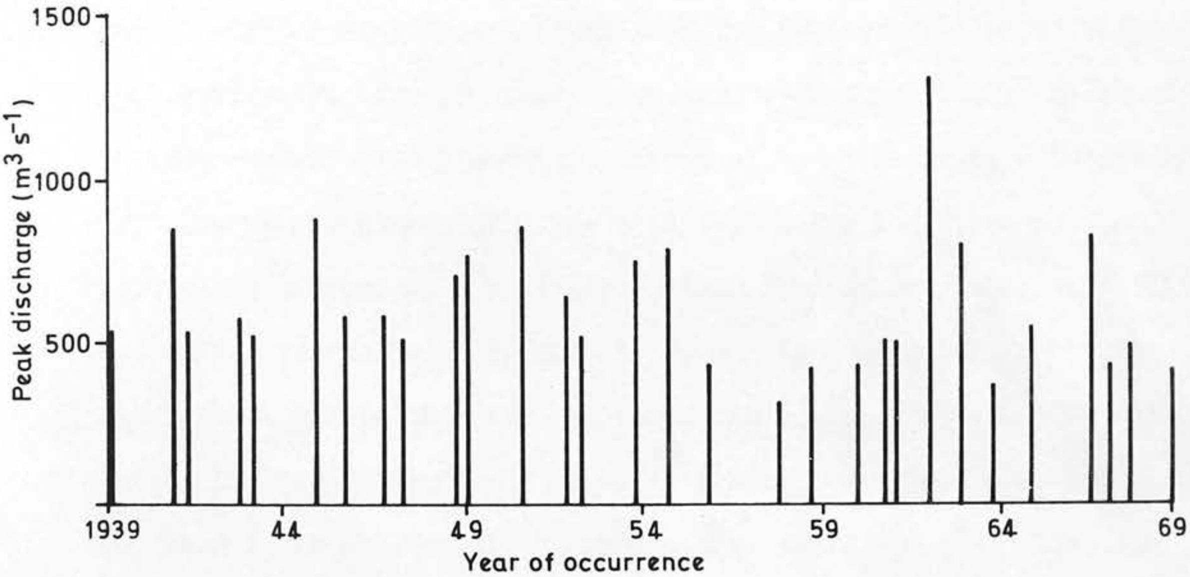

FIGURE 2.3 ANNUAL PEAK FLOWS AT FRIARS CARSE FOR THE PERIOD 1939 - 1969, SEE TEXT FOR DERIVATION.

first sorting operation. The use of such a technique places considerable reliance on journalistic sources. However, in the Dumfries area , a chance combination of circumstances presents an alternative technique for assessing these historic flows. These circumstances are that accounts of inundation habitually use the extent of flooding in a steep narrow street in Dumfries, named Friars Vennel as a local guide to the magnitude of the flood. This street runs at right angles to the river from the frequently flooded Whitesands area towards the town centre. Such expressions as "the flood reached the clog makers" (1966) and "lapped the steps of Mogerley's butchers shop" (1962) are common as a means of expressing the distance the flood water reached up the street. This form of reference is still used in the reporting of recent floods and as a magnitude value for these events can be obtained at Friars Carse, it is possible to relate crudely the magnitude of the flood at Friars Carse to the extent of the flood in Friars Vennel. For example, at 1275 m^3s^{-1} discharge at Friars Carse the flood reaches Mogerley's; therefore, the historic flood of 1863 which reached the old town walls was considerably greater than 1275 m^3s^{-1}. From this the magnitudes of historical floods have been estimated. It is suggested that this method uses the most finely divided and reliable "natural" gauge in the area and that better estimates of the magnitude of historical ungauged floods would be difficult to obtain in Nithsdale. This section of the search brought to light severe floods of 1910, 1926, 1930 and 1933. In addition, of course, it confirmed the more severe floods of the 1939 to 1969 record, the floods of 1940, 1944, 1950, 1962 and 1966. Three of these nine floods could be further confirmed by wall markings.

2.2.1.3 Wall Markings

A series of flood marks exist on the walls and farm buildings in the vicinity of Friars Carse. These marks show, for some floods, the peak height reached by the floodwaters together with the date on which the flood occurred. These stages were measured by levelling to Friars Carse datum and were then converted to discharge using the same methods applied earlier to adjust the Auldgirth Bridge record. Marks had been made for the 1910, 1930 and 1933 floods and these convert to stages of 4.72, 5.24 and 5.33 m respectively at Friars Carse.

All of these data sources were in complete agreement with the exception of the reports of the 1910 flood. The 1910 flood was discussed in newspaper reports in connection with the 1962 flood when the latter was described as being ".. the biggest since 1910 ..". However, according to the wall markings the 1910 flood was a full metre lower than the 1962 flood refuting the newspaper claim and in fact meaning that in the intervening half century there had been a number of floods greater in magnitude than the 1910 flood. An examination of the incomplete referencing system used by the local newspaper office suggested a likely explanation. The referencing system gives the dates and some details of local natural phenomena such as rainfall. For 1910, rainfall is noted as being the heaviest recorded in the area and flooding is also noted. It is possible that on seeing this the reporter assumed that the 1910 flood would also be the greatest recorded.

It is clear, however, that rainfall conditions at Dumfries have little bearing on the flood regime of the River Nith, which is determined by rainfall at least 50 km to the north. For this reason, it has been decided not to accept the 1910 flood as the biggest on record, but rather to take the wall record as the most accurate account of this event.

2.2.2 The Record of Flood Events

The history of flood events has now been extended from 1910 to 1969. Flooding has been identified during the period 1910 to 1939 in the years 1910, 1926, 1930 and 1933. Although these floods were not recorded in a systematic hydrometric sense, nonetheless it is possible using the methods discussed above, to rank and identify the magnitudes of these floods for which the estimated discharges were 700, 1,050, 900 and 1,000 m^3s^{-1} respectively. From documentary evidence relating to the period 1939 to 1969 a series of floods can be identified occurring in the years 1940, 1944, 1950, 1962 and 1966.

For the period of prime importance in this enquiry, starting with the erection of the flood protection works in the Nith Valley in 1946, a continuous discharge record is available. To make full use of this record, i.e. to confirm the "documentary floods" and to identify any further floods during the period it is necessary to determine the discharge at which the levee is overtopped. This figure is required for two further purposes: firstly, for use with the flood frequency analysis to determine the return intervals between minimum floods under the protected system; secondly, as an aid to the determination of the volume of water that will overspill onto the floodplain from floods of known discharge. (This is required as an input to the model discussed below).

The bankfull capacity of the floodway was of concern to the DAFS' engineers at the time of the design and construction of the protection levees. However, proof by observation of their calculated estimates of the critical discharge was not found until the flood of 1966, when the floodway filled to the crest of the levee and the system failed. The DAFS' engineers who made these observations are clear in their statements that the levee failed, it was not overtopped. The discharge at which it failed, 815 m^3s^{-1}, is not in disagreement with the calculated critical discharge estimates and was gained from the discharge recorded at Friars Carse immediately upstream. As earthbank levees of the type installed in the study area are prone to failure before apparent overtopping, it was considered that a critical discharge value of 815 m^3s^{-1} could be accepted.

This critical discharge level was used in conjunction with the flow records at Friars Carse and verified the occurrence of the 1950, 1962 and 1966 floods. In addition, a further flood was identified as occurring in September 1962. The existence of this flood was later confirmed by discussion with floodplain users. From the time of the erection of the flood protection works in 1946 there is a confirmed flood history of 4 events (Figure 2.4) one in each of 1950 and 1966 and two in 1962.

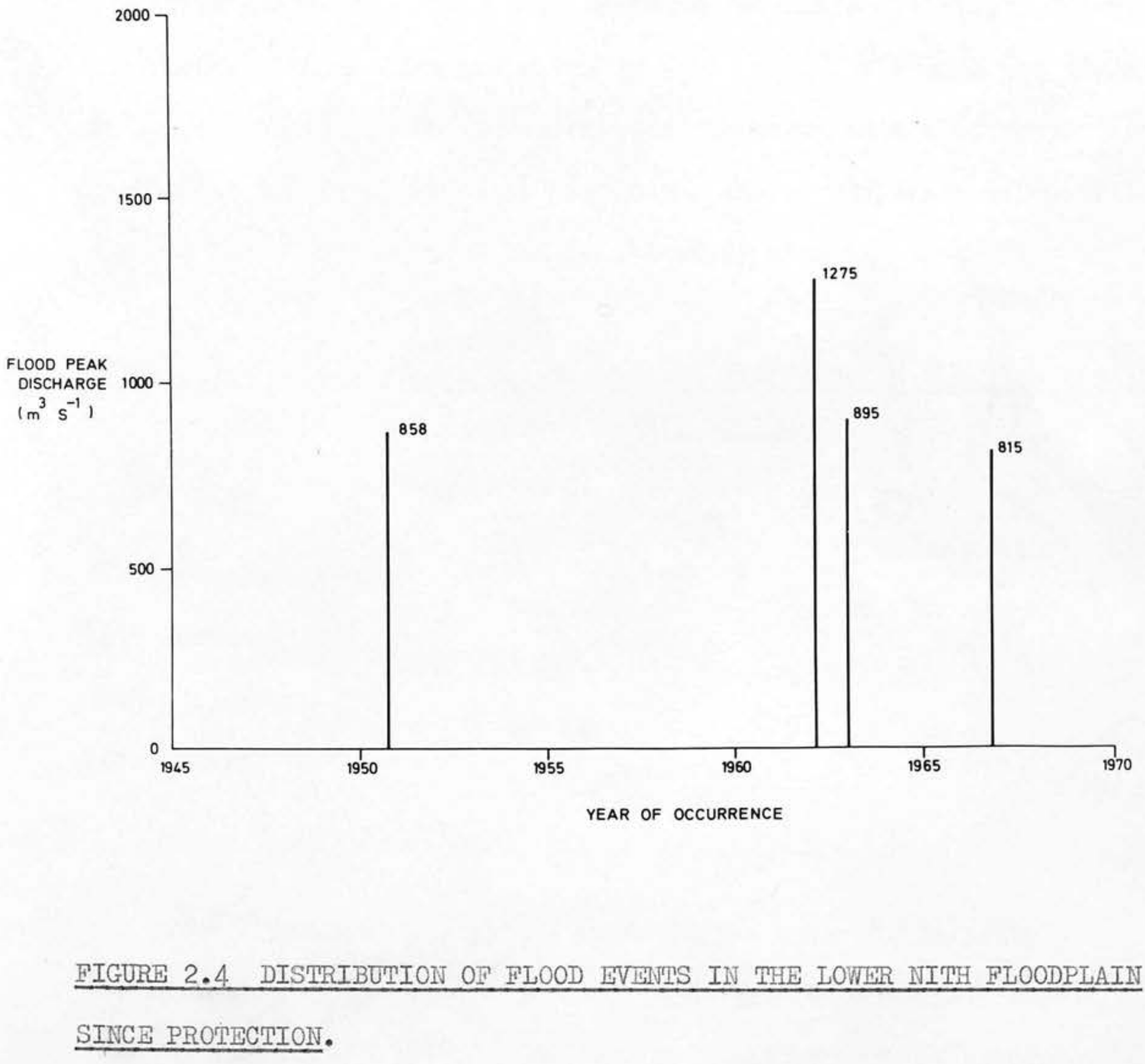

FIGURE 2.4 DISTRIBUTION OF FLOOD EVENTS IN THE LOWER NITH FLOODPLAIN SINCE PROTECTION.

2.2.3 Data Available on the 1946 to 1969 Floods

Few data concerning either the impact of flooding on the farm operations or the characteristics of the floods on the Nith floodplain may be directly derived from the gauged records of river flow. For the four floods that form the core of the flood history in question the flood stages and their corresponding discharges at Friars Carse are known. These data are given in Table 2.1. Although the stage data are specific to the location, the discharge data will apply throughout the study area, as the number and significance of contributing streams below Friars Carse and in the study area are low.

Table 2.1 Dates, stages and discharges of floods in the Nith floodplain, 1946 to 1969

Date	Stage (m)	Discharge
7th September, 1950	5.15	858
16th January, 1962	6.00	1,275
30th September, 1962	4.69	895
14th August, 1966	5.065	815

The discharge data give a guide to the apparent severity of the flooding. The flood of January 1962 was considerably larger than that of August 1966. However, as shall be seen subsequently, the acceptance of severity and magnitude as synonymous may be valid in an urban context, but it is not always valid in rural flood situations.

The flow data thus far collected identify basically only the pattern and frequency of flooding. To gain data on the impact and extent of these four floods a questionnaire survey was devised and interviews were conducted with the planning and agricultural institutions[1] concerned with the area, and with the individual floodplain managers, (see Appendix 2 for results). The survey confirmed one major point that data on flood impact and extent were incomplete at least in this area. Questionnaire survey could not identify for one single flood, both the extent of the flood and the amount of damage caused.

This seems to be due to the fact that very different information is deemed worthy of retention by the various resource managers. For instance Figure 2.5 shows the extent of the January 1962 flood, from which it was possible to determine depth of inundation at various parts of the floodplain, extent of flooding and the impact of the flood on individual farmers as measured by percentage of farm area inundated or as an index derived from extent and depth. These data on the flood extent were prepared and retained by the County Planning Department because the 1962 flood was one of the largest in living memory in the area. However, no record was kept of the extent of the 1950, the autumn 1962 or the 1966 floods, yet the Nith farmers claim, and logic supports them, that the January 1962 flood had little real

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[1] In particular with the National Farmers Union, the Agriculture Advisory Service and the County and Borough Planning Departments.

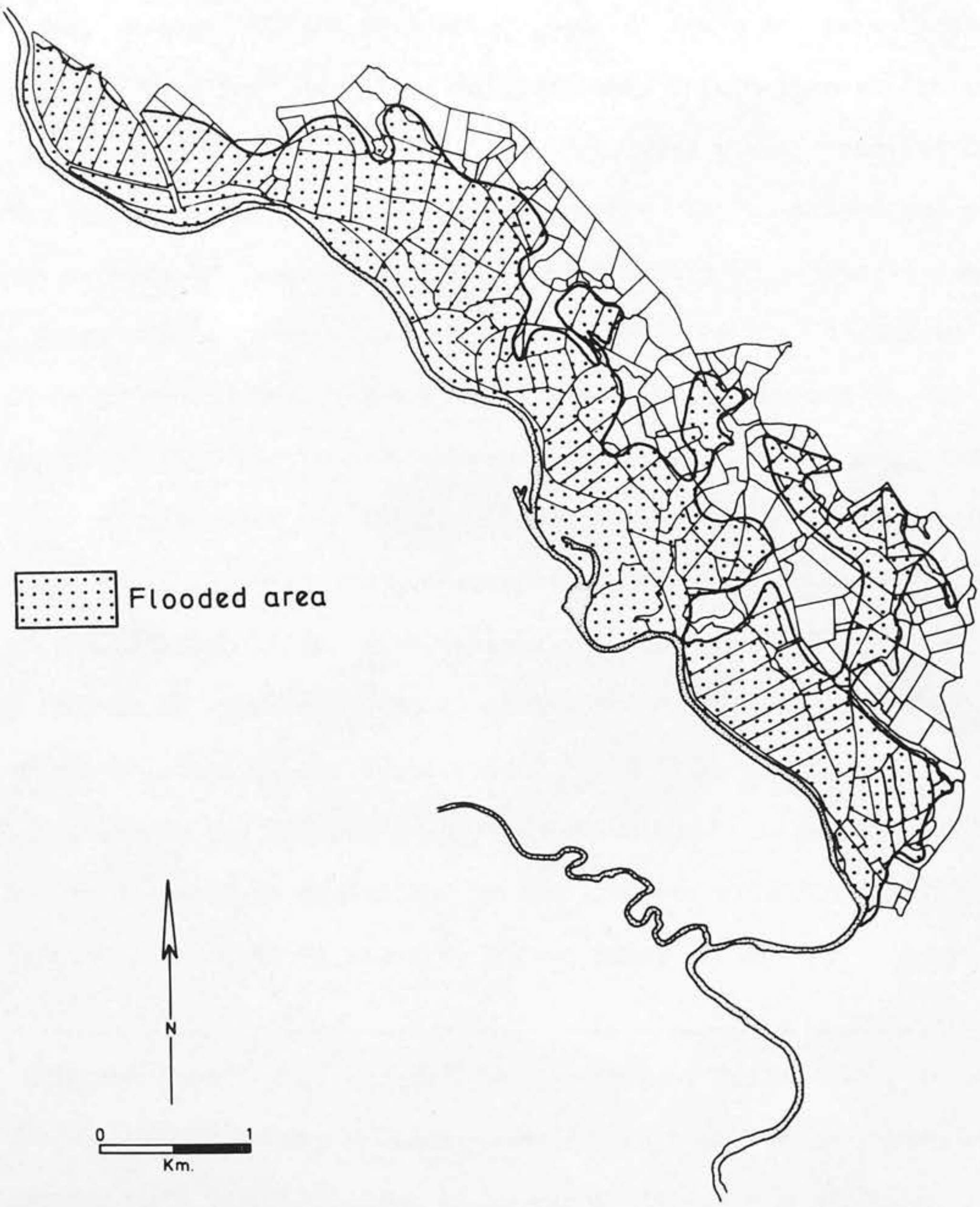

FIGURE 2.5 EXTENT OF THE JANUARY 1962 FLOOD IN LOWER NITHSDALE.

impact because it occurred in winter, whereas the 1966 flood was severely damaging to crops and equipment[1]. In comparison to the information available from farmers concerning the impact of the 1962 flood, that of 1966 is well documented, at least for some farms, in relation to direct damage. Unfortunately information on the physical aspects of the floods is, in comparison, very poorly recorded by the farmers. Whilst some can readily provide data on extent and others can provide information on depth, the majority when pressed are clearly unsure of the flood details. Thus for the floodplain as a whole it proves impossible to gain adequate information on the impact of flooding through conventional questionnaire techniques.

To determine the total extent and specific areas flooded by these four floods it was necessary to produce a mathematical model of the flooding in the Nith valley. In this case the need for such a tool is emphasised by the necessity to evaluate the physical characteristics of the hypothetical flood pattern that would have prevailed in the absence of protection works. In general the need for such a tool is emphasised by the literature Harding (1972) discusses the need to identify hazard zones accurately. Brown,

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[1]Although more damage was suffered to fences, drains etc., in the 1962 flood, animal feeding systems, such as the pig feeding system at Auchencrieff Farm were also destroyed in 1966. In addition, machinery was severely damaged after the 1966 flood due to attempts to recover silt laden crops. Low crop damage in 1962 meant low consequent machinery damage.

Contini and McGuire (1972) in their examination of floodplain economic models "assume that the physical effects of floods of given heights are predictable with certainty", a naive assumption that these authors might have questioned had they referred for instance to the problems of flood mapping discussed by Wolman (1971).

2.3 A Floodplain Model

Several approaches are available for determining the extent of flooding. Most are based on the concept that the valley becomes the channel in times of flood. One widely used method is Chezy-Manning, which has been hypothetically applied by Porter (1972) in the United Kingdom. However, these principles might apply to unprotected upland streams having a small floodplain but must be rejected for the larger valleys such as Nithsdale, for the following reasons. Firstly, the cross section required to pass the 1,275 m^3s^{-1} flood of January 1962 is far smaller than the mapped flood event. The area covered by this flood is shown in Figure 2.5. If it is assumed that this was in fact a moving body of water of slope[1] equal to that of the floodplain, .0015, of high n value, .1, and having a cross section of say 3 by 400 m equal to the average flood extent, then on Chezy-Manning principles, the flow would be over double the discharge actually measured at the peak flow in January 1962. Secondly, the macrostructure of the Nith floodplain, discussed below, prevents it from being viewed simply as a large channel.

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[1] The Chezy-Manning formula is described in Section 2.4.2.

Thirdly, the duration of the flooding is significantly longer than the time taken to pass the flow greater than channel capacity, clearly indicating that one is dealing with a storage situation rather than a simple flow situation.

The model that was developed treats the floodplain as a storage area where overspill volumes of water are distributed. It can be considered as a physical model, as it is based on topographic and hydrologic data. It was tested against the data for the 1962 flood. Although the model used in the Nith study was modified to take advantage of specific items of local information, it remains generally applicable. Questions of the general applicability of the model will be examined in the concluding Chapter. Because a single run of the model requires the solution of numerous equations, the model has been programmed to run on the IBM 360/50 computer at the Edinburgh Regional Computing Centre.

Little work has been carried out in the past in an attempt at the detailed simulation of the "filling" effect of water escaping from the river channel onto the floodplain. Therriot (1971) has been involved in this type of work and views the floodplain as a macrostructure, as discussed below. However, in Therriot's work the routing of the floodwaters over the floodplain is attained by hardware modelling the overflow of water onto the floodplain and not by mathematical modelling on the basis of overspill volume and microstructure.

The path of the flood is considered to follow a sequence of field inundations determined almost entirely by the difference in height of adjacent fields. This sequence of inundation is called the flood series. The flood series is constrained by the division of the floodplain into large sections called flood units. Within a flood unit, the flood sequence is determined by relative field height alone. The flood series starts from breaches in the levee, the locations of which are known from past floods. The extent to which a flood will inundate the area depends on the volume of overspill. The overspill volume is moved along the flood series field by field. As larger areas are flooded, so the stage drops. Eventually, the height of floodwater in a field is not sufficient to flood the next field in the series and the flood area has been determined. In those cases where the next field is flooded, a new flood depth is calculated by equating the volume of water required to fill the next field to the new flood depth with the volume of water generated by the drop in flood stage in all the fields thus far flooded.

2.3.1.1 Nith Floodplain Macrostructure, Flood Units, Location of Breaches and the Flood Series

The floodplain of the River Nith cannot be considered simply as a large flat area or a large area of uniform slope because it is divided by privately erected floodwalls, a natural ridge and a railway line. The area within the floodwalls which protect Netherholm contains no further obstructions to the flow of floodwater. The spread of the water is limited only be height differences in the fields. This area forms what shall be termed a flood unit, the basic unit in the Nith macrostructure. A flood unit is an area of land containing no significant artificial or natural barriers to the spread of floodwater. Within a unit the extent to which fields of differing heights will be inundated depends upon the volume of the inundating water and the topography of the unit.

The land to the south of Netherholm Farm is divided by the wooded ridge of Carnsalloch which runs westward from Templand Hill Farm to the Nith itself, some 300 m beyond Carnsalloch House. The floodplain to the south of the ridge is relatively flat and again is considered a flood unit where the spread of floodwater will be limited by differences in field elevation only. The land to the north of Carnsalloch as far as Netherholm, constitutes a further unit. The situation here is less clear cut in comparison to the already named units, due to the presence of remnants of individual attempts at protection. However, the four sections of levee found in this unit are not continuous and are no longer considered functional enough to require further subdivision of the unit.

The land to the north of Netherholm is divided into two units, that lying to the north of the Glasgow-Dumfries railway line, and extending as far as Friars Carse, and that lying to the south of the railway. Although this latter area is large and the passage of water is constricted by the raised land around Bellholm Farm, there is little real evidence for further subdivision. Floodwater moves freely between the levee and Bellholm Farm through a 250 m gap.

The macrostructure of the floodplain is shown in Figure 2.6. The division into these five units is a basic step in the construction of the model. Standard topographic data are used in this division into flood units. It is assumed that each of the units floods discretely and that only when the floodwaters in a breached unit reach the limit of the "floodwall" separating it from an adjacent unit will the latter start to flood. Such an assumption is supported by the fragmentary evidence gained by interviews with the farmers. Units are not used analytically. The barriers are treated as constraints in the model.

The operation of the model depends upon the location of the first field to be flooded. The flooding occurs through breaches in the levees. It would be possible to number the different sections of the levee and allow the flood programme to "start" at any point using a random number generation technique. However, some information on the location of the breaks is available and this information has been used. The 1966 flood caused breaches in the Rigfoot unit at point A in Figure 2.6. The floodwaters were therefore initially routed into this unit and thereafter into the other units. However, the large January 1962 flood caused the protection system to fail at three points, once again at A in Rigfoot unit, but also at points B and C in Kerricks unit as shown in Figure 2.6. Due to the paucity of data available, the discharge of the Nith at which multiple, as opposed to single, breaks would occur was set approximately midway between the values for the 1962 and 1966 floods. The two important

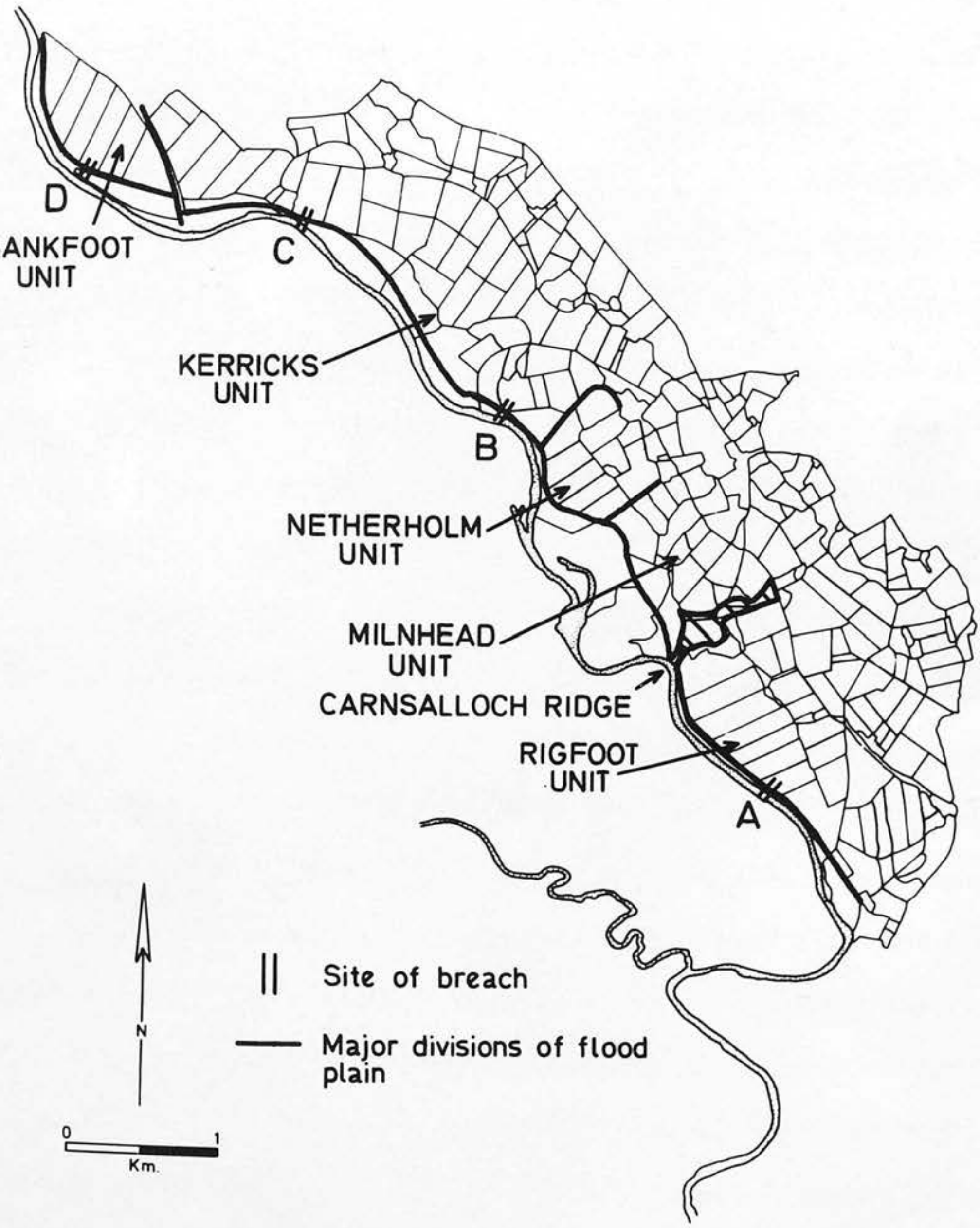


FIGURE 2.6 MACROSTRUCTURE OF THE NITH FLOODPLAIN AND THE LOCATION OF KNOWN BREACHES.

values used in this part of the model are that at which single breaching occurs, 815 m^3s^{-1}, and that at which the multiple breaches occur, 990 m^3s^{-1}.

The flood units discussed above are a constraint on the flood series. It is not possible for the floodwaters to move directly from one field to an adjacent field <u>across</u> a unit boundary. The units flood only after the water has entered an unbounded edge of the unit. For example, floodwater in Kerricks unit can only enter Netherholm unit by flowing behind the eastern edge of the northern private floodwall. The location of the breaches are known to be at points A, B and C in Figure 2.6. From this information and with knowledge of the height of each field in the floodplain, the flood series can be constructed.

The flood series is a listing of the field by field flood sequence dependent upon the type of breaching that occurs. The first field in the series is the one adjacent to the levee in which the breach takes place. The next in the series is the one adjacent to and lower in height than that flooded, having the greatest height difference with the flooded field. If no adjacent field is lower than that flooded, then the next in the series is the adjacent field having the smallest difference in elevation above the flooded one. As the series develops it is necessary to examine all the fields along the flood edge, but the principle remains the same. The next field is always adjacent to one already in the series. It will be the field lowest in elevation of all the fields next to the flood edge except where a flood unit boundary intervenes.

2.3.1.2 Floodplain Microstructure and the Routing of Floodwaters

Routing of floodwater is also influenced by the microstructure of the floodplain. It is assumed that each of the fields in the floodplain is flat. The floodplain is therefore envisaged as a number of platforms. This use of a step function can be justified on a number of grounds. Firstly, in a large floodplain the field forms a discrete flood entity due to the edge factor discussed below. Secondly, the field is the management unit belonging to a particular farmer, to whom its flooding can be related. Furthermore, the effectiveness of the model as an economic tool is limited if field data such as land use cannot be incorporated when needed at a later date. The data required for each field were area and height. The area of each field was determined for 25 inch to the mile (1:2,500) O.S. maps. These data were converted to metric values for use in the programme. The height of each field was taken as the mean of a number (2 to 12) of spot heights determined by standard levelling techniques. To relate the data to a field, each field in the floodplain was numbered. Figure A2.1 in Appendix 2 gives the numbers allocated to each field in the floodplain. Tables A2.1 and A2.2 give details of field areas and mean heights.

The routing of the floodwaters from field to field could not be made solely on the basis of the flood depth and the difference in height between adjoining field. More formally, if the height of the nth field is Y_n and the depth of the floodwater in that field is Z_n, then the use of an equation of the form:

$$Y_n + Z_n > Y_{n+1} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.1)$$

as a means of deciding if field n+1 will flood is unacceptable. It is unacceptable because each field is surrounded by a small ridge caused by (a) remnants of ditch, embankment and hedged field boundaries, (b) fencing with consequent water and wind-borne debris together with more dense areas of ineffectively grazed vegetation at the base of the fencing, and, (c) raising of the land by plough turns and the non-removal of crops at the boundary edge. All of these contribute to ridges of varying height around fields and suggest the introduction of an edge factor. For the purpose of this model this was set, from measurements in the area, at 0.1 m and thus the decision equation becomes:

$$Y_n + Z_n + 0.1 > Y_{n+1} \qquad \qquad (2.2)$$

This equation decides whether field n+1 will flood dependent upon the depth of water in field n. Which field is n+1 is decided by the flood series. Field n+1 is adjacent to the flood edge, lowest in elevation and will therefore flood with a minimum increase in flood depth, Z_n, in field n.

Two problems remain outstanding. The first is the calculation of the volume of overspill into the floodplain. The second is the derivation of an algorithm to determine the height of the floodwater in field n. This is required for use in the decision equation (2.2) which determines the extent to which a particular overspill volume will inundate the flood series.

The calculation of the volume of overspill of floodwater onto the floodplain was made from stage hydrographs at Friars Carse. These were converted to discharge hydrographs using the appropriate stage-discharge relationship (Figure 2.2). The area under the hydrograph curve and above the critical discharge of 815 m^3s^{-1} was calculated, thus giving the overspill volume. The repetition of these calculations for floods of differing magnitudes formed the basis of a graph of peak discharge against overspill volume. This is shown in Figure 2.7. This calculation has assumed that the peaks would be independent at discharges above the critical discharge. There is no evidence from the Friars Carse flow records that this is an invalid assumption for the Nith. However, if this form of overspill calculation was used in a situation where the flood hydrographs overlapped, inaccuracies would arise in proportion to the degree of overlap.

If it had been important to examine a flood situation where there was a double peaked hydrograph, it would have been possible to calculate an overspill volume for that specific hydrograph and enter this into the model. This point is of some importance in relation to the general application of this type of model. Also significant is the question of the time distribution of the overspill volume. This item is of interest to the research worker who is concerned with the rate of areal spread of floodwater in a floodplain. The total overspill hydrograph can be split into volumes of overspill per unit time over the overspill duration. These volumes can be routed

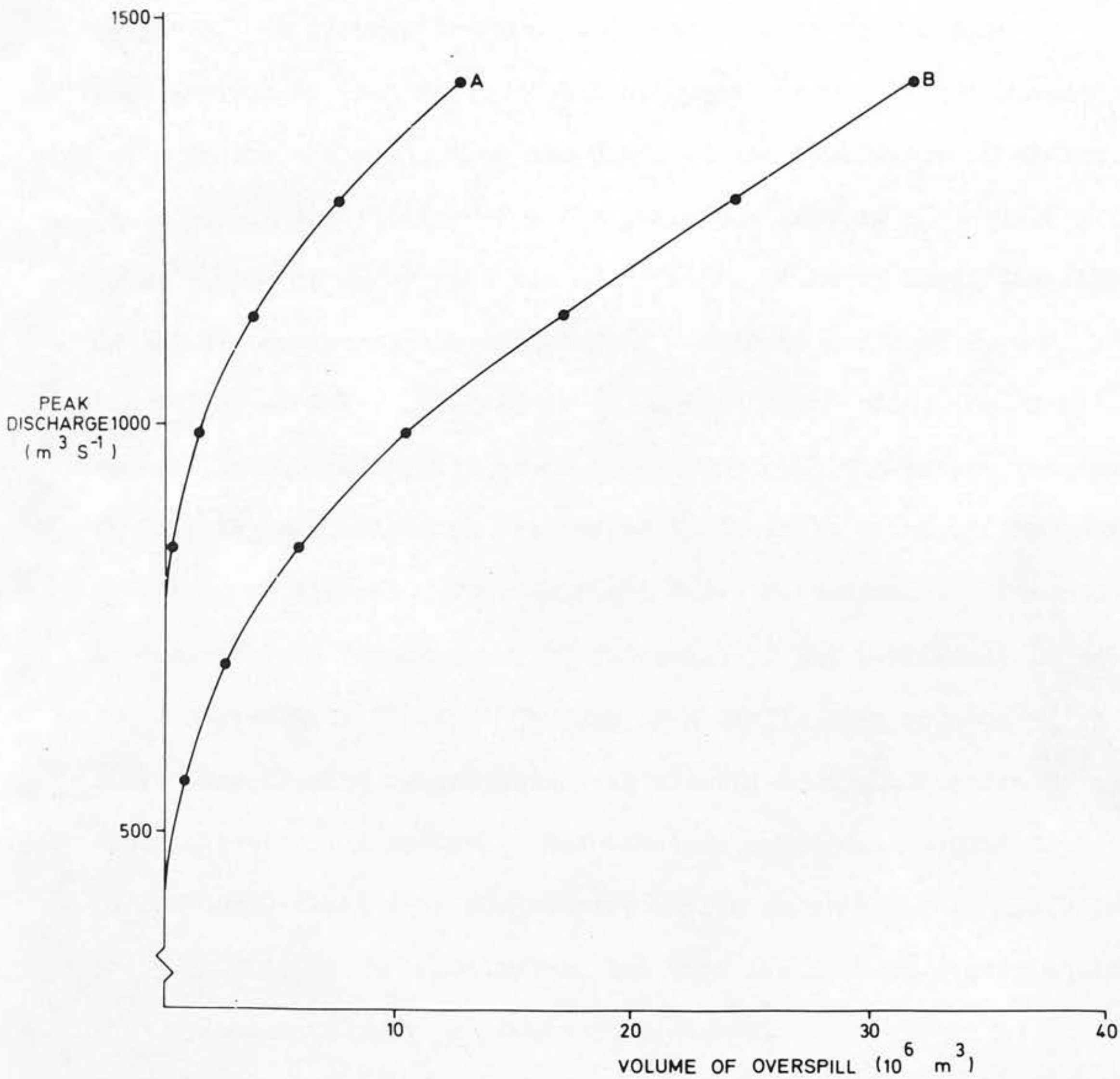
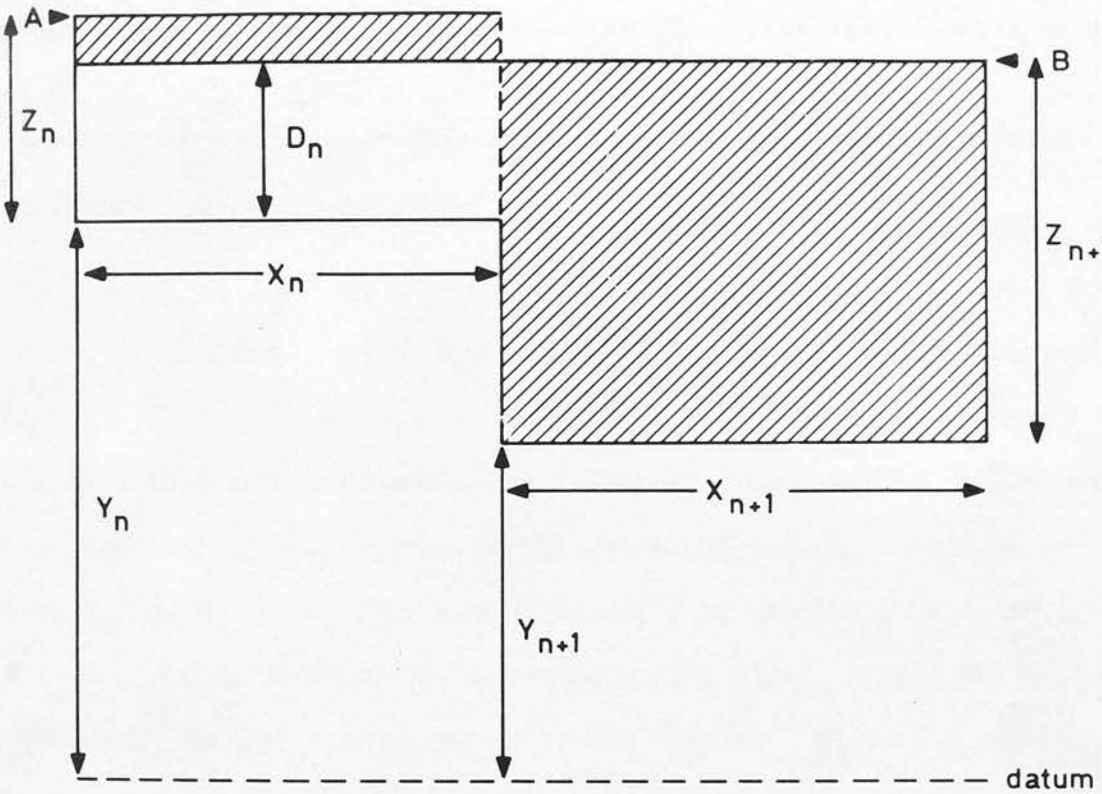


FIGURE 2.7 RELATIONSHIP BETWEEN PEAK DISCHARGE AND OVERSPILL VOLUME, A WITH PROTECTION, B WITHOUT PROTECTION.

cumulatively and the extent of the flood and other physical characteristics read out after each volume has been routed. The final extent of the floodwaters routed in this manner is the same as that derived by routing the total overspill volume in one operation.

In the calculation of the depth of the floodwater at different times during the flood series the principle used is that given a known volume of water on a field or fields of known area, the depth of the floodwater can be calculated. This is achieved by equating the volume of water involved in an unknown depth reduction in all of the fields flooded (whose areas are known) with the volume required to fill the next field in the series to the same unknown flood depth as the other fields. The new flood depth determined in this manner is entered into Equation 2.2 to determine if the next field in the flood series will flood. The use of a single step mode in which fields are flooded progressively is clearly a simplification of the flood situation in nature. Nevertheless, one would expect that the fields would flood in a progressive series in relation to their level and proximity to the floodwater, but that field flood events would overlap and would not be single step events.

The principles on which the routing of floodwater is calculated are best illustrated by an example. Figure 2.8 shows the situation in fields n and n+1. Field n+1 is being flooded and it is of interest to determine the depth of floodwaters following the inundation. It will be remembered that fields one to n are already flooded. Let the area of the field n be X_n, its height Y_n and the present depth



A is the level of the flood water in field n. prior to the flooding of field n+1

B is the subsequent level of flood water in fields n. and n+1

FIGURE 2.8 THE FLOODING OF FIELD n+1 FROM FIELD n. SEE TEXT FOR DETAILS OF MEASUREMENTS.

of floodwater in it Z_n. Let D_n be the depth of floodwater in field n, following the flooding of field n+1. Thus:

$$D_n = Y_{n+1} + Z_{n+1} - Y_n \quad \text{.......................} (2.3)$$

In single step mode D_n stabilises and the two shaded volumes shown in Figure 2.8 can be equated thus:

$$\left[\sum_{n}^{1}(X_n)\right] (Z_n - D_n) = X_{n+1} (Y_n + D_n - Y_{n+1}) \quad \text{.......} (2.4)$$

The left hand term represents the volume of floodwater in fields one to n involved in the decrease in flood height from Z_n to D_n. The term $Y_n + D_n - Y_{n+1}$ is a reformulation of the flood depth in field n+1, Z_{n+1}, in terms of the known values Y_n and Y_{n+1}, and the desired unknown D_n thus:

$$Z_{n+1} = Y_n + D_n - Y_{n+1} \quad \text{.......................} (2.5)$$

Solving Equation 2.4 for D_n gives:

$$D_n = Z_n \sum_{n}^{1} (X_n) - (X_{n+1} (Y_n - Y_{n+1})) \;/\; (\sum_{n}^{1}(X_n) + X_{n+1}) \quad \text{......} (2.6)$$

the right hand term can clearly be simplified to $\sum_{n+1}^{1} (X_n)$ thus Equation 2.6 becomes:

$$D_n = Z_n \sum_{n}^{1} (X_n) - (X_{n+1} (Y_n - Y_{n+1})) \;/\; \sum_{n+1}^{1} (X_n)) \quad \text{............} (2.7)$$

Examination of the terms in Equation 2.7 show that data concerning flood depth and field heights are required for only fields n and n+1. The only item that need be derived from values for each field in the flood series is area. This formulation means that a considerable reduction in the complexity of the equations and thus in the time of computation has been achieved.

Flood depth in field n+1 is calculated from Equation 2.5. The model routes the flood along the flood series using Equation 2.2, Equation 2.5, using terms derived from Equation 2.7, calculates the new inputs for Equation 2.2. When Equation 2.2 is no longer satisfied the routing of the flood is terminated and summary statistics for the flood are calculated.

The output from this model gives the identification number of the field flooded, the depth of water in each field, whether the field would eventually drain free due to floodwater spilling onto lower fields, the total number of fields flooded and the total area of the flood.

2.3.1.3 Testing the model

It is clearly important to test any model before it is applied. This can be difficult to achieve in the case of some theoretically advanced models, since empirical data are often unavailable, but is simplified where a specific case is being investigated. In the case of the Nith, data concerning the January 1962 flood are available as are fragmentary data on the September 1962 and 1966 floods. It is possible to examine the model from three viewpoints, rationality, reproducibility and comparability.

In terms of its rationality, it is difficult to call attention to any part of the model. It is based on proven concepts. The data have been measured for the purpose of the model and are specific to the floodplain. Clearly, the model can be criticised for its relatively large data requirements and perhaps for its simplicity. One can for instance pose questions concerning the amount of floodwater that infiltrates into the floodplain and the effect of this volume of water on the routing techniques which have been applied in this study of the Nith. The answer here would of course be to draw attention to the importance of scale in hydrology. Undoubtedly infiltration of some of the floodwater would occur. However, the floodplain is a mere 1 percent of the catchment area, the duration of overflow in even the largest floods, is only a few hours and much of the floodplain is likely to be already partially saturated due to prior rainfall. Furthermore these small volumes of water which infiltrate will be compensated for by the water flowing onto the floodplain from minor sources such as Barrows Burn, the flow of which cannot enter the main river until after the passage of the flood wave, due to the operation of flood valves in the levee.

In terms of the reproducibility of the results, the model has been satisfactory. In its final form the model will produce similar output given similar input. This does not support the validity of the model, but rather supports the functional efficiency of the programme.

To compare the output of the model with the flood situation as it occurs in the field, one must refer to Figure 2.5, in which the extent of the January 1962 flood is delineated and compare this to the extent of the same flood as calculated by the model (Figure 2.9). It is apparent that the model agrees closely with observed data for the area south of Sandbed. Flooding is predicted in the area to the north east of Auchencrieff Farm and this is confirmed from the original map and by local farmers. However, close examination of the flood pattern in this area reveals slight differences in the predicted and actual patterns of flooding. This is due to the complex nature of the flooding in this part of the floodplain, arising from the opposing forces of the mainstream floodwater pushing into this area under and around Auchencrieff Bridge and the floodwater from Barrows Burn. This stream is noted by DAFS engineers and by many of the farmers in the southern and eastern parts of the floodplain as being prone to minor flooding. It drains quite a large area of moss and intensively drained farm land, yet has no effective outlet during times of flood.

To the north flooding in the Netherholm area corresponds well with the predicted area of flooding. Small tongues of floodwater have covered areas to the east of the main mass of water. The most southerly of these extensions was made through Wellington Bridge flooding a small area to the north west of Kirkton village, known as Lake. This area of flooding was not identified in the model and local interview evidence suggests that this area may have in fact suffered insidious flooding as opposed to river flooding. The most northerly of these extensions of the floodwater is identified in the model in the flooding of fields 98 to 100. Further to the

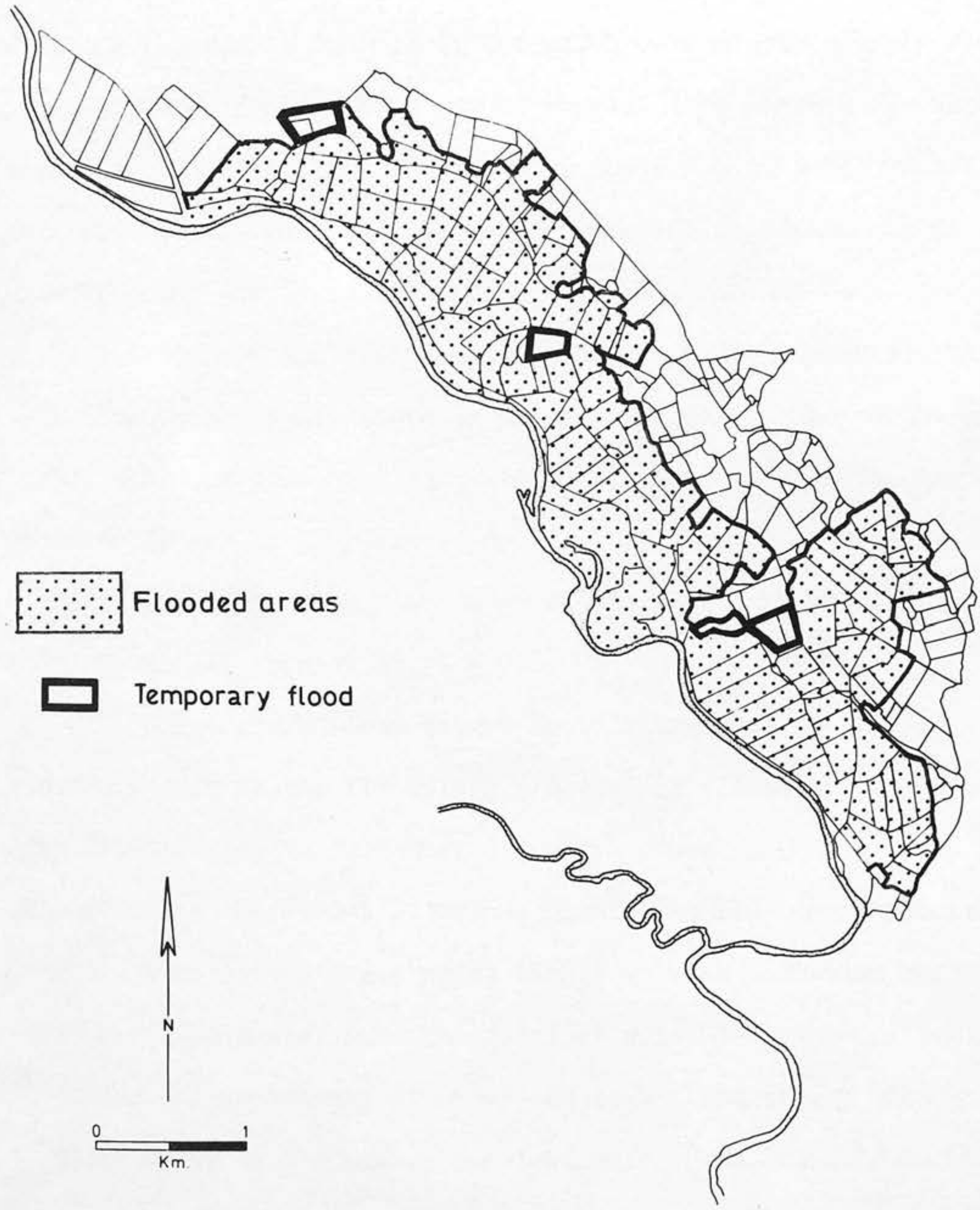


FIGURE 2.9 THE EXTENT OF THE JANUARY 1962 FLOOD AS COMPUTED FROM THE UNCALIBRATED FLOOD MODEL.

north, fields 16 and 26 in Foregirth Farm are correctly identified as being the only fields that did not flood in January 1962. At the northern tip of the floodplain, one can identify an area of 10 fields, mainly within the Bankfoot unit, which are not identified as being flooded in the model, but which were almost totally flooded in 1962. Two explanations can be suggested to account for this discrepancy. The first is that when the model is being used in multiple breach mode, the volume of overspill floodwater is divided equally among the three start points. This may not be a true representation of the situation in reality. It is possible that more floodwater might escape in the upper areas. The northerly fields that are predicted as flooding all had a floodwater depth of about 50 cm and as they are 17 to 18 m O.D., it is clear that volume restrictions halted the "flooding" of the fields in the Bankfoot unit, which lie from 19 to 21 m O.D.

A point which lends weight to this argument is that in the more southerly area of the floodplain a number of fields are considered to have flooded when in fact they did not. Thus, for this area, a lower proportion of the overspill volume might have been more appropriate. However, running the model using larger volumes indicates that the advance of floodwater into the Bankfoot unit, is not sensitive to increases in the volumes of water and that flood depths well in excess of those noted by farmers in Kerricks unit would occur if northerly progress of floodwater was to be achieved. A second and more likely explanation is that a fourth breach occurred at point D in Figure 2.6.

Damage to the levee was experienced at this point and it seems that the commonly offered explanation that this breach was caused from within the levee is erroneous. As no local evidence of a further breach at this point could be obtained, and as an objective assessment of the model proved satisfactory, it was decided that a four way routing should not be substituted for the three way routing.

The comparative examination of the patterns of flooding shown in Figures 2.5 and 2.9 is an instructive yet subjective method of assessing the value of the model. A more objective appraisal can be made by allocating each field to one of three categories:

(i) Where a flood event has been correctly identified in the model.

(ii) Where a flood event has been predicted by the model, but which did not in fact take place.

(iii) Where a flood event has taken place, but which has not been predicted in the model.

Table 2.2 summarises this categorisation. Table A2.3 shows the allocation of each field into one of the above categories. 23 events are incorrectly identified, the events in 133 fields being accurately identified, giving the success rate of 85.3 percent. In defining the area flooded, however, the "overflood" predicted in the southern area compensates for "underflood" in the north. A net deviation of only three fields between observed and predicted gives a success rate of 97.9 percent. If the calculation is repeated using areas rather than numbers of fields (Table A2.1) a difference of 21.39 hectares is found. Again, this is an accuracy of prediction of over 96 percent.

The depth of flooding calculated in each field in the 1962 flood is recorded in Table A2.3. Since, as has been noted above, the flood edge follows closely the predicted flood edge, it follows that the flood depth calculation in the model will be in general agreement with the flood depth in the field as calculated by height differences between the flood edge and the field in question. These floodwater depths are confirmed by the Nith farm managers.

Table 2.2 Summary statistics by field number comparing the areas flooded in the January 1962 flood, with the flood areas determined for the same flood using the model

	I Flood event correctly identified in the model	II Flood event incorrectly predicted	III Failure to predict a flood event
			1-10
	11-27		
		28-29	
	30		
		31	
	32-36		
		37-39	
	40-74		
		75	
	76-78		
		79	
	80-81		
		82-84	
	85-101		
		102	
	103-119		
		120	
	121-155		
Total	133	13	10

percentage accuracy 85.3

percentage accuracy including compensation between II and III = 96.1

2.3.2 The Physical Characteristics of Flooding on the River Nith

If the distribution of flood events shown in Figure 2.4 is again referred to it can be seen that three floods occurred in the decade 1960-1969, whilst only one further flood, 1950, has occurred since the erection of the protection works in 1946. This is further evidence perhaps, for the claim by Harding (1972) that the 'sixties' have been particularly flood prone years which have helped to focus public interest on flooding and its control. Of the four floods, three are remarkably similar in size. These are the 1950, September 1962 and 1966 floods, having peak discharges of 858, 895 and 815 m^3s^{-1} respectively. The mean of these floods is 856 m^3s^{-1}, virtually the same value as the 1950 flood, and the remaining peaks are within 41 m^3s^{-1} (4.7 percent) of the mean peak discharge. Reference to Figure 2.7 indicates that change in volume of overspill is relatively insensitive to change in peak discharge at early stages in the curve, and this is reflected in the similar statistics which apply to these three floods. An overspill volume of 0.75×10^6 m^3 is calculated, which results in the flooding of 44 fields covering a total of 153.46 hectares (see Figure 2.10). The floods covered land worked as parts of Whitehall, Rashgill Park, Brownfield, Templand Hill, Rigfoot and Auchencrieff. Of these, Auchencrieff suffered most heavily. Almost half the floodwater area lay within this farm[1]. Six fields are

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[1] The areas computed as being flooded in the 1966 and September 1962 floods are confirmed by the present owner and manager of Auchencrieff Farm. No map of extent made at the time is available.

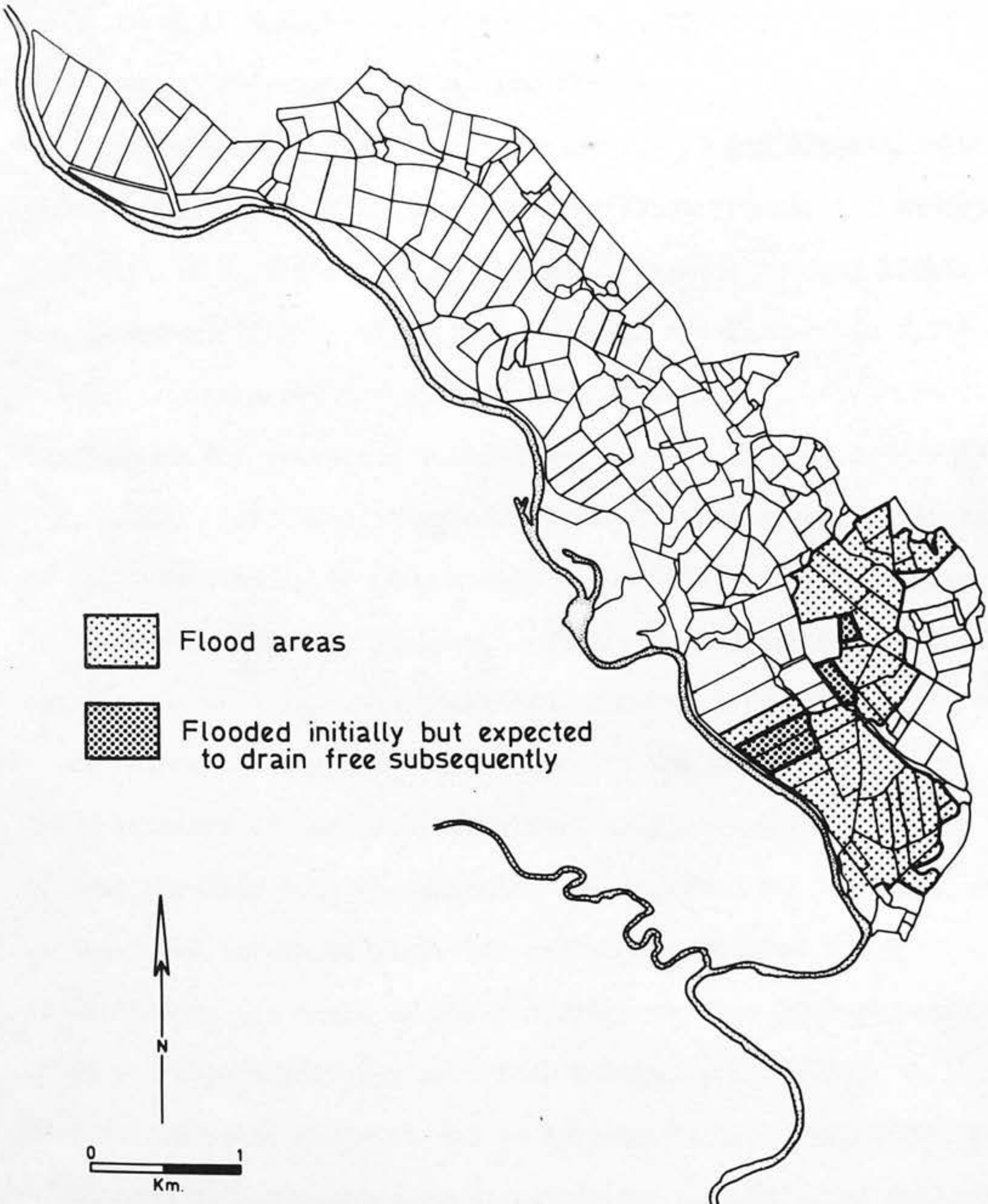

FIGURE 2.10 THE COMPUTED EXTENT OF FLOODS WITH PROTECTION HAVING AN OVERSPILL VOLUME OF 0.75×10^6 m^3.

expected to have low depth of floodwater retained only by the edge factor discussed above (2.3.1.2). Twenty-six fields are expected to flood to more than 0.5 m and 4 to beyond 1 m. The maximum flood depth is calculated to be 1.27 m. Clearly in terms of depth of flooding, these were not severe floods.

In contrast, the flood of January 1962 was considerably greater than even the largest of these three floods, its estimated[1] peak flow of 1,275 m^3s^{-1} being 380 m^3s^{-1} or 42.4 percent higher than the September 1962 flood. This flood is the largest in fifty years and has an estimated overspill volume of 7.57 x 10^6 m^3. The duration of the overspill calculated from the stage hydrograph of the January 1962 flood (Figure 2.11) is nine hours from 2100 hours on the 15th January to 0600 hours on the 16th January, peaking at 0100 hours on the 16th January. In this flood 578 hectares of farmland on 16 farms were inundated, some to depths of over 3 m.

Since the time of the erection of the protection works, 1,038 hectares of land are calculated to have been inundated. Most of this flooding took place in the 1960's, when 884 hectares, 85.2 percent of the total inundated area, are calculated to have flooded. It is clear that on the basis of the flooding over the last 25 years, some farms suffer considerably more than others, particularly in the south of the floodplain and adjacent to Barrows Burn. Private protection works have not been successful on the one occasion when they might have retarded floodwater.

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[1] The floodwater in fact submerged the stage recorder at Friars Carse shortly before the peak discharge stopping the clock.

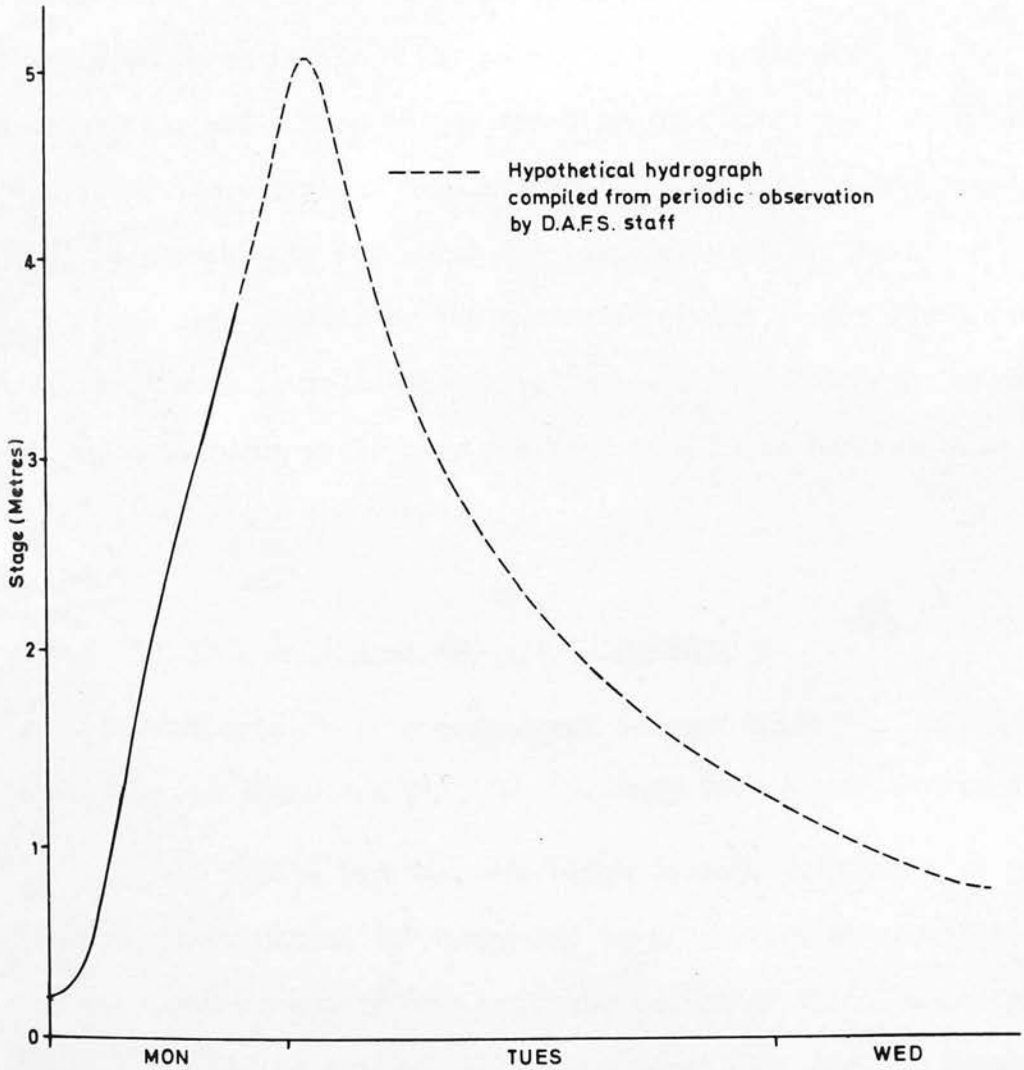

FIGURE 2.11 STAGE HYDROGRAPH OF THE JANUARY 1962 FLOOD TAKEN FROM THE FRIARS CARSE RECORD.

2.4.1 The Characteristics of Flooding without Protection

Thus far the dates and the magnitudes of the floods that have overtopped the protection works in the Nith floodplain have been identified. The paucity of the data available has led to the development of a model designed to determine the extent of these floods. It is now necessary to identify the periodicity and extent of the flooding that would have occurred if no protection works had been erected. When this is achieved, it will be possible to determine the basic changes in the flood pattern that have been created by the protection works. The first and most important step towards this objective is to determine the discharge at which flooding would have occurred if a levee had not been constructed along the river.

2.4.2 The Calculation of Bankfull Discharge

Three methods were considered through which the bankfull discharge[1] of the River Nith in the study area could be determined.

(i) To relate bankfull discharge to such parameters as the mean annual discharge and to discharges at specific recurrence intervals. The values of these parameters could be determined for the River Nith and the bankfull discharge computed from them. This method has the advantage that fieldwork would not be required.

[1]The term "bankfull discharge" has not been clearly defined in the literature. As a result, bankfull discharge may vary for one cross section. Various definitions of bankfull discharge will be discussed subsequently and that chosen for this study expanded.

(ii) To observe bankfull stage on the river and thereafter determine the flow at that time from the discharge at Friars Carse.

(iii) To undertake field measurements and compute from these the value of bankfull discharge.

The first method was rejected because the relationships between bankfull discharge and parameters such as recurrence interval are gross over simplifications. Bankfull discharge has been the subject of a number of studies and has been estimated to have a recurrence interval of from less than one year to ten years. The work of Nixon (1959), Dury (1959; 1961) and Brush (1961) illustrates this range in value. Such a generalisation would introduce a large source of variation into the analysis.

The second method was rejected mainly on the grounds that there is no guarantee that a bankfull discharge would occur during the study period. In fact the river records for the period 1970 to 1972 indicate that such an event occurred only once during this period and that was at 0300 hours on 2nd February 1970, when accurate observation would have been impossible.

It was accepted, therefore, that the most suitable method was to obtain estimates of bankfull discharge based on measurements of channel characteristics. An established slope area formula is the Chezy-Manning formula, which is discussed in Meinzer (1942), Chow (1959), Wilson (1969) and Eagleson (1970) amongst others.

The discharge of a river reach is determined from the product of the cross-sectional area of the reach and the average velocity of the water passing through that cross section. In 1775 Antoine de Chezy suggested that the velocity component, v, could be determined from the formula:

$$v = C\sqrt{r.s} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2.8)$$

where C is a frictional component, r the hydraulic radius and s is the slope of the water surface. The formula below (2.9) where n is a roughness coefficient, was suggested in 1890 by Manning as a means of determining the frictional component of the Chezy formula.

$$C = (1.486/n)r^{1/6} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2.9)$$

Nemec (1972) discusses alternative techniques for the determination of C. All of these methods use n or a derivative such as 1/n or y. Manning's equation is the most commonly used and in combination with Equation 2.8 forms the Chezy-Manning equation:

$$v = (1.486/n)r^{\frac{2}{3}}\ s^{\frac{1}{2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2.10)$$

It is assumed that the Chezy-Manning equation is valid for the non-uniform reaches encountered under natural conditions, despite the original development of the equations for conditions of uniform flow in which the water surface profile and the energy gradient are parallel to the stream bed. Depth, area and hydraulic radius are assumed to be uniform throughout the reach. These are standard assumptions made by all users of the technique under natural conditions. This is discussed in Wilson (1969) and Dalrymple (1967).

With the exception of the n value, all of the components of the equation are measured in the field. The n values until recent years have been determined by reference to tables (Linsley, Kohler and Paulus, 1958) giving stream and bed descriptions and associated n values. Choosing n in this manner can lead to serious errors even with experienced hydrologists. Barnes (1967) has alleviated the difficulty to some extent by back calculating n from discharge measurements made from current meter readings. For each n value, Barnes has augmented the description of the reach with a diagram of the cross section, details of the bedload and photographs of the reach. Essentially, however, this remains a development which improves the information on which to base a subjective assessment.

A more objective technique has been developed by Limerinos (1970) and by the Prague Hydraulic Research Institute. It relates both size and distribution of bed particles to Manning's n value. Limerinos measured bed particle size at the minimum and intermediate diameters of the particles. The values of the 16th, 50th and 84th percentiles and a weighted combination of all three were used as a measure of bedload size distribution. Limerinos developed eight equations which take the general form:

$$n/r^{1/6} = .0926/(a + b \log (r/d)) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2.11)$$

where a and b are constants and d is a measure of bed particle size. In his work, the best results were obtained using the 84th percentile of the minimum particle size. The equation specific to these measurements is:

$$n/r^{1/6} = .0926/(0.76 + 2.0 \log r/d^{1}_{84}) \quad \ldots\ldots\ldots\ldots \quad (2.12)$$

where d^{1}_{84} is the 84th percentile minimum diameter. The 84th percentile minimum diameter was used in the Nith study to determine n.

2.4.2.2 <u>The Definition of Bankfull Discharge</u>

The identification of the point at which bankfull discharge is achieved is critical to this part of the study. Various definitions of what constitutes bankfull discharge have been offered. Schumm (1960) for instance suggests that vegetation changes may serve to identify the bankfull stage but this is inappropriate in the Nith area due to the artificial control of vegetation in the whole of the floodway. Leopold, Wolman and Miller (1964) state that bankfull discharge is not attained until the floodwater stage reaches the floodplain. Brush (1961) and Speight (1965) consider that the maximum break of slope marks bankfull stage whilst Wolman (1955) favours the point at which the width to depth ratio is at a minimum. In this study the choice is closely related to the stage at which significant flooding occurs. This begins as the floodwater reaches the floodplain and so the author favours, and has used, the rather subjective method of identification suggested by Leopold <u>et al</u> (1964).

2.4.2.3 Field Methods

The field work necessary to determine the bankfull discharge of the River Nith in the study area comprises three stages.

(i) Surveying of river cross sections.

(ii) The determination of the slope of the water surface.

(iii) The sampling of the bedload material to determine n.

Seven cross sections of the river were measured at approximately 1 km intervals. The location of the measured points is shown in Figure 2.12. The site of each cross section was marked so that slope measurement and bottom material sampling could be carried out at a later date. A light waterproof rope graduated in metres was used to determine the location of the points at which depths were taken. The depth measurements were made using sectional metal poles graduated in 10 cm divisions. Estimation of the depth could be made to within 2 cm as each section was carefully waded. From the waters edge the survey was continued using level and staff to the point assessed as bankfull stage.

Standard levelling techniques were used to measure the slope of the water surface. This survey was carried out at a time of high flow and was continuous over the length of the river from above Bankfoot Farm to below Auchencrieff Farm.

The bed material was sampled by randomly selecting 100 cobbles from the river bed at each cross section. The sampling was made by selecting the first cobble touched by hand along a random number of points over the cross section. This method is recommended by Benson

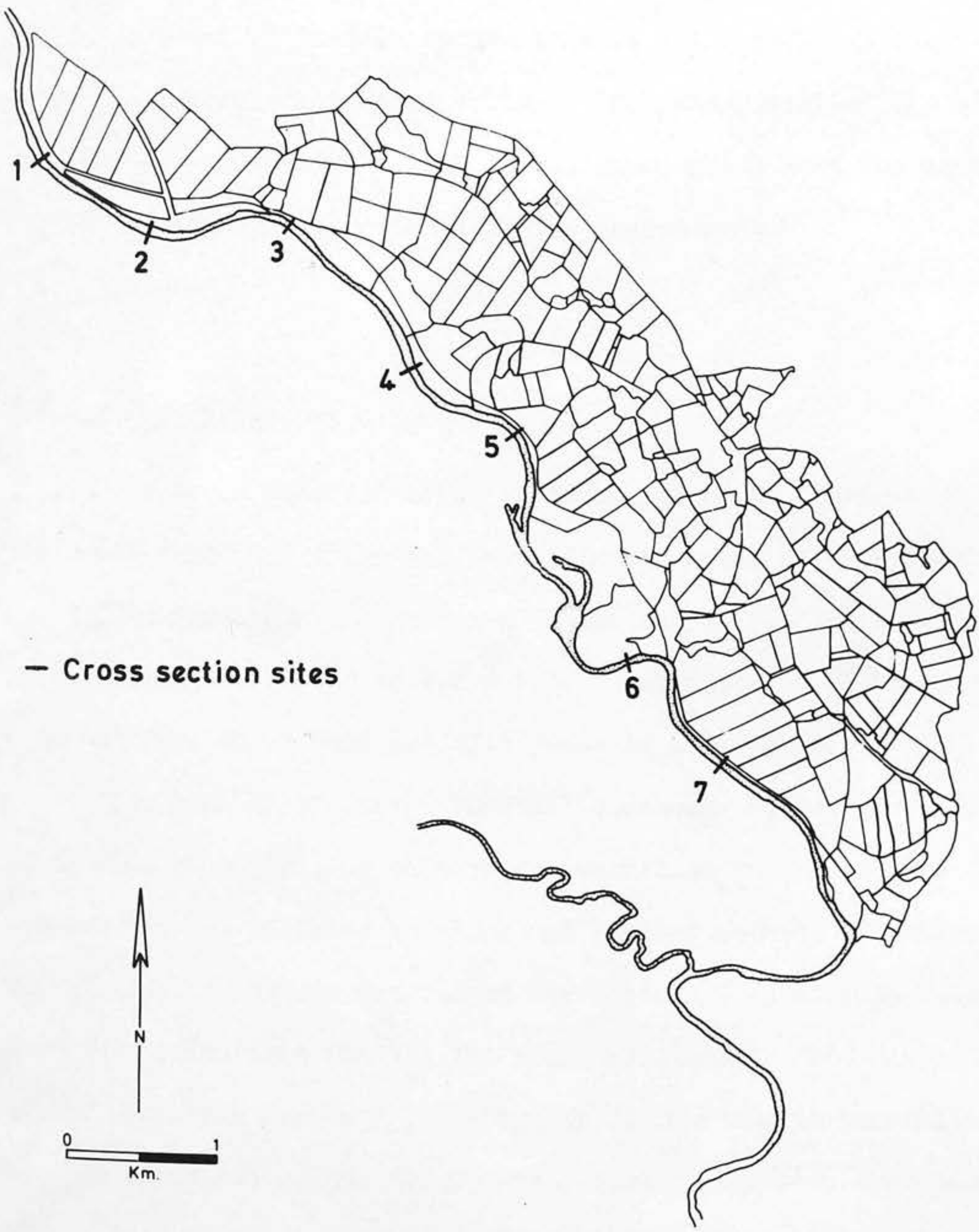

FIGURE 2.12 LOCATION OF THE CHEZY MANNING CROSS SECTIONS AND THE BED LOAD SAMPLING SITES.

in Dalrymple (1967). The sample number, 100, is suggested by Wolman (1954) and is used by Limerinos (1970). This number is to some extent a matter of convention. When the measurements are listed in order of magnitude, the chosen percentile value, in this case, the 84th, is readily apparent as it coincides with the magnitude number of the same value. The measurement of the minimum diameter was made using a fish length board which held the cobbles firmly and allowed a precise diameter measurement.

2.4.2.5 Results

The seven measured cross sections are shown in Figure 2.13, and the cross sectional areas and the hydraulic radii of each section calculated from these, together with the slope, d^1_{84} and n values for each section are listed in Table 2.3. Estimates of bankfull discharge obtained from these data are also given in this Table.

The mean of the seven bankfull discharge estimates is 419 m^3s^{-1}. It is perhaps surprising to note the variation in the results (σ 44.3 m^3s^{-1}) despite the use of waded sections and bedload methods of determining n. The bankfull discharge determined for Section 6 is considerably lower than that calculated for all the other sections. This disparity is almost certainly due to the difficulty of identifying bankfull stage at this point, where the floodplain slopes gently into the channel over a long distance. In the past this area has flooded much more frequently than other parts of the floodplain and even today no attempt

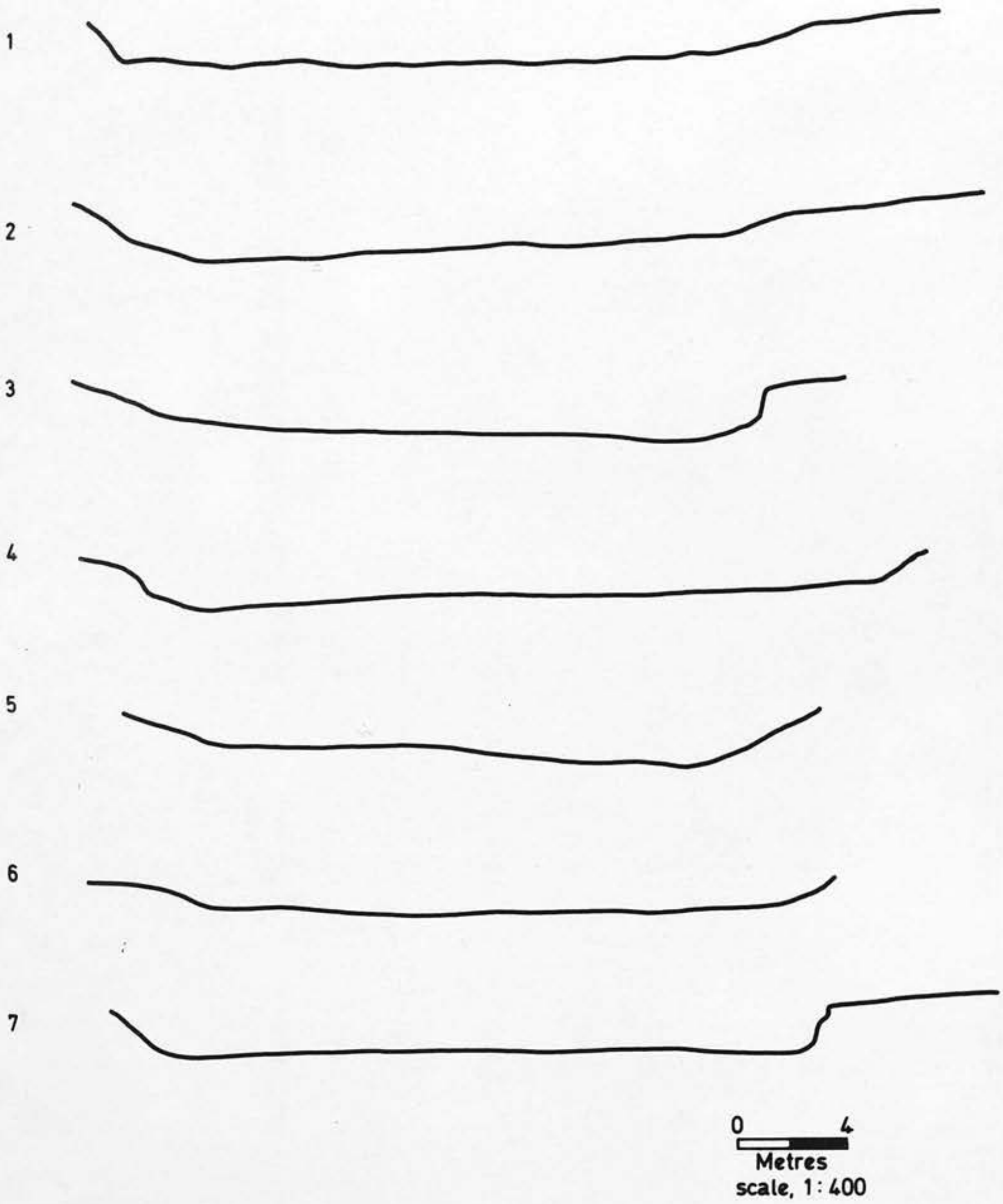

FIGURE 2.13 CHEZY MANNING CROSS SECTION PROFILES.

Section Number	Area (m^2)	d^1_{84} (cms)	n	Hydraulic Radius (m)	Slope	Discharge (m^3s^{-1})
1	152.4	7.9	.035	2.539	.0028	431.4
2	174.0	11.4	.038	2.716	.0024	445.0
3	165.5	13.2	.039	2.966	.0026	450.1
4	150.4	6.1	.033	2.505	.0024	413.8
5	130.1	6.1	.033	2.502	.0037	444.6
6	120.7	4.4	.031	2.237	.0021	322.6
7	139.5	9.3	.036	2.615	.0033	425.3

Table 2.3 Data used in determination of bankfull discharge

has been made to protect this area. The computed discharge value for Section 6 would appear not to make an accurate contribution to the calculation of bankfull discharge for the River Nith. Bankfull discharge was therefore determined from the remaining six sections, the value obtained being 435 m^3s^{-1}. Although this figure is only 3 percent greater than the discharge value computed from the results of all sections, the standard deviation of the estimate is now reduced to 14 m^3s^{-1}, despite the reduction in sample numbers. For this study the bankfull discharge is considered to be 435 m^3s^{-1}.

2.4.3 The Pattern of Flooding Without Protection

From the results of the work on the discharge at bankfull stage, it is possible to analyse the annual flood peak discharge diagram (Figure 2.3) and abstract from it those floods which have a discharge of over 435 m^3s^{-1}. In the period 1946 to 1969, 16 of the 23 annual peaks would have caused flooding. This hypothetical flood pattern is illustrated in Figure 2.14.

It would not be accurate to suggest that this frequency of flooding, one flood in 1.44 years, represents the long term frequency of bankfull discharge in the study area. A total of 37 occurrences of bankfull discharge can be detected if the entire record, as opposed to the record of annual peaks, is used. This places the frequency of bankfull stage at 0.62 years. In contrast to overlevee flooding, it would be fair to consider that discharges would have to be well above

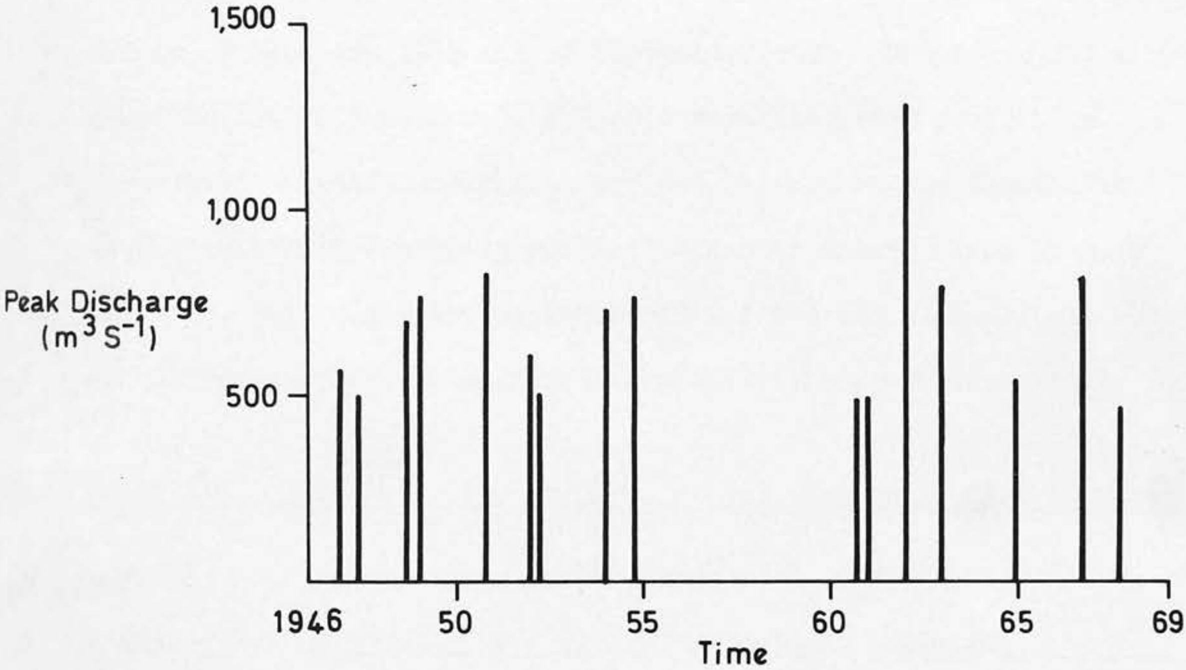

FIGURE 2.14 THE PREDICTED FLOOD PATTERN WITHOUT PROTECTION FOR THE PERIOD 1946-1969.

bankfull to cause significant flooding without protection. The annual series floods of over 435 m^3s^{-1} is then a good representation of the frequency of severe overbank flooding in the study area. Table 2.4 below, lists the dates and estimated peak discharges of flood events from 1946 to 1969 that would have inundated significant areas had protection works not been constructed. In addition to the annual peaks which cause flooding it is necessary to add two further floods of February 1948 and of September 1962. These are not annual peaks but it is considered, subjectively, that they would have contributed significantly to the flood pattern on the floodplain. Both have stages exceeding bankfull stage at Friars Carse by more than 1 m, and indeed the September 1962 flood has already been noted as having actually caused flooding despite the protection works.

Table 2.4 Dates and discharges of floods that would have occurred without protection

Date	Discharge (m^3s^{-1})	Date	Discharge (m^3s^{-1})
22.11.46	563	29.10.54	764
5. 4.47	495	14. 9.60	487
26. 9.48	691	30.11.60	481
3. 1.49	756	16. 1.62	1275
7. 9.50	858	8.12.62	779
19.12.51	614	12.12.64	523
7. 3.52	504	14. 8.66	815
4.12.53	730	9.10.67	464

In earlier Sections, the lack of data available on flood extent made necessary the development of a model. Now the hypothetical nature of the enquiry requires the modification of the model to take account of this critical discharge level of 435 m^3s^{-1}. A new curve of overspill volume against peak discharge, assuming no protection is derived (Figure 2.7 above) in the same manner as is described in Section 2.3.1.2. It is assumed that with the exception of the levee, the major topographic features remain the same. The flood occurrences discussed above are used as input data to the modified model to determine the extent of flooding that would occur if protection were not available.

In the assessment of the numbers of floods that would have occurred without protection, three situations were considered. Firstly, the number of floods that results from annual peak flows. Secondly, floods that result from the annual series together with those floods of the partial series that are assessed as serious - that is having a stage 1 m over bankfull stage. Thirdly, the series of floods that result from any discharge in excess of bankfull discharge. In assessing the area of farmland that would have been flooded in the 1946 to 1969 period, the same three lists of flood events based on the above criteria are used. The resulting estimates of inundation areas are shown in Table 2.5.

The extent of inundation from annual floods in this period is estimated to be 2,890 hectares covering 732 fields. This area is increased by 16 percent (479 hectares) on the inclusion of the areas that would have been flooded by the significant partial floods of

1948 and 1962. The resulting estimate of 3,369 hectares of flooded land is likely to be the most valuable and accurate assessment of the real impact (in areal terms) of flooding without protection. A further 19 floods would have occurred, but these would have barely exceeded the calculated bankfull capacity of 435 m^3s^{-1}.

Table 2.5 Summary statistics of the areas flooded with protection in the 1946 to 1969 period. The three assessment criteria are discussed in the text

Flood numbers by size category	Area (hectares) per flood	Area (hectares) per category	Criteria
5	59	295	
2	71	142	
1	153	153	
2	189	378	
3	240	720	
2	265	530	
1	672	672	
16		2890	(i) annual
1	167	167	
1	312	312	
18		3369	(ii) annual and significant partials
19	43	817	
37		4186	(iii) all floods

The flood depths calculated for the smaller floods, such as the one which would have occurred on the morning of the 9th October 1967, are low. The maximum depth calculated for this 60 hectare flood is 0.64 m and almost one third of the fields are indicated as likely to drain free as the water flows to lower lying areas of the floodplain. Larger floods such as that of August 1966, having an overspill volume of 4.4×10^6 m^3, would have created flood depths of close to 3 m in some fields. In the remarkable flood of January 1962, when the flow of the river was more than three times the bankfull discharge for a short time and twice the bankfull discharge for several hours, flood depths of 2 to 4 m would have been widespread and depths in excess of 4 m would have occurred for short periods in the low lying fields at the bottom of Milnhead unit.

Data which might have been of guidance in establishing the outline of the flooding without protection are not available. There is no basis on which to decide the locations at which flooding would commence. It is assumed therefore that over bank flooding would occur at the same points at which flooding has commenced in recent years. The extent of all unprotected floods is delineated on this basis. Four of these flood patterns for floods having peaks of 470, 815, 895 and 1,275 m^3s^{-1} are shown in Figure 2.15.

2.5 Comparing the Physical Characteristics of the Two Flood Sets

The most obvious change in flood pattern following protection is the reduction in the frequency of flooding. Between 1946 and 1969, three annual peak flows caused flooding. There was a fourth flood

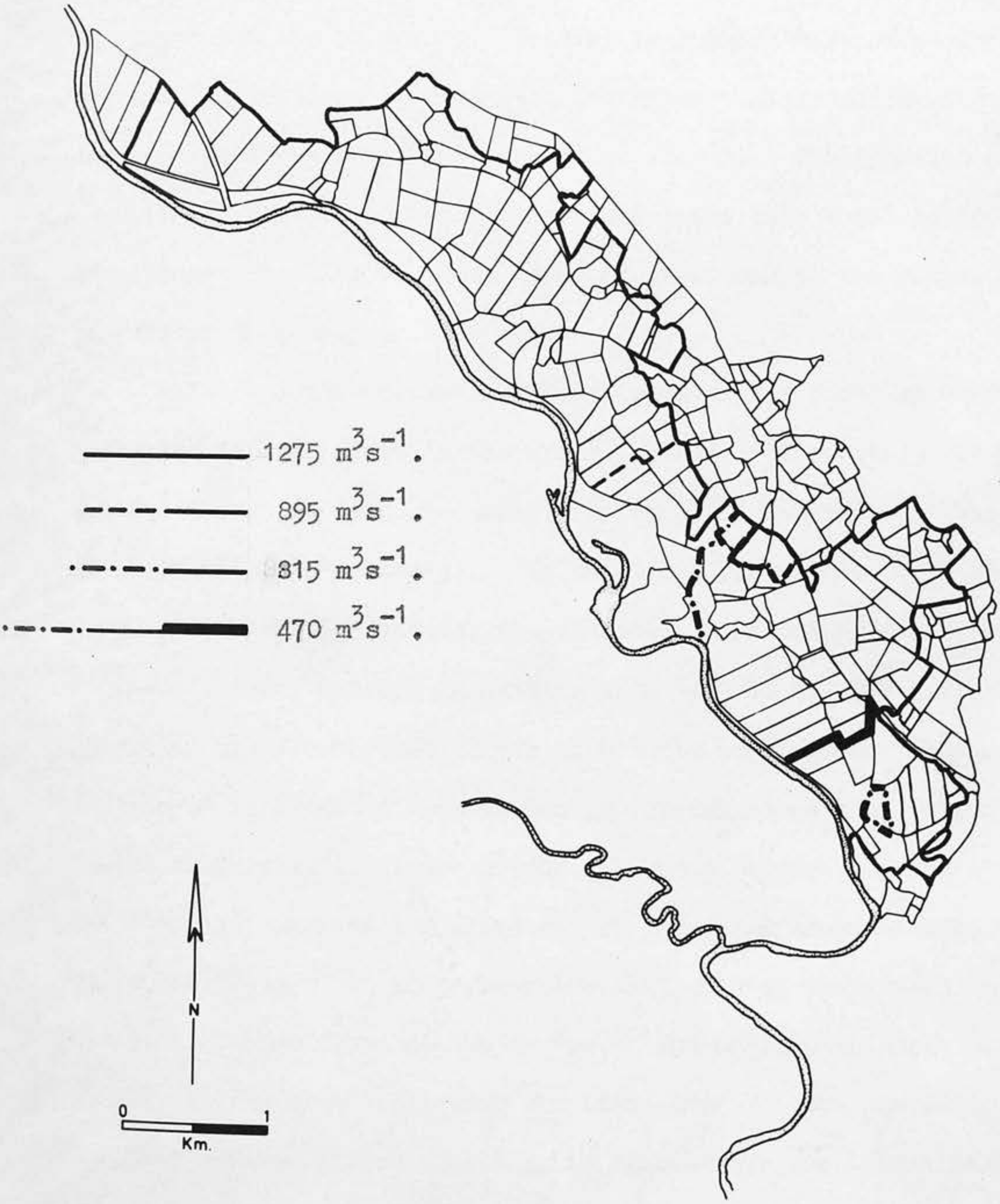

FIGURE 2.15 COMPUTED EXTENT OF FOUR FLOODS WITHOUT PROTECTION.

event if all high flows are considered. The historic frequency of flooding is therefore once every 7.67 years based on annual peak floods, falling to 5.75 years if all flows in the period are considered. In comparison the pattern of flooding that would have existed under "natural" conditions is characterised by much higher flood frequencies. Annual high flows would have caused 16 floods. The addition of significant partial series floods would raise this total to 18. Significant flooding would be expected every one to two years. The calculated frequency is 1.28 years.

Clearly, this decrease in the frequency of flooding must be reflected in a decrease in the areas flooded. Protection has reduced the flood area to 1,038 hectares, one third of the value without protection (3,369 hectares). In the 1960-1970 decade, when flooding appears to have been severe, the reduction in flooding was from twelve to three events, cutting inundation from 1959 to 884 hectares. Changes in extent are clearly not on the same scale as frequency changes. This is to be expected because the protection stops that subset of floods comprising the lower discharge events between 435 and 815 m^3s^{-1}. The "average" unprotected flood covers a smaller area than the "average" protected flood. It is to be noted that without protection, the duration of high flood depths is low. The water will drain more quickly to the river following the flood event. The protection works have the adverse effect of retaining floodwaters for longer periods than might otherwise have been the case.

2.6 Conclusions

It seems useful to draw some points of conclusion from the work of this Chapter:

(i) It is apparent that although the protection works have reduced the flood hazard, measured crudely as total flood events and areas inundated, considerable hazard remains. The flooding though less frequent now consists of larger flood events which still occur on average once in six years.

(ii) Information of any value on the flood hazard could not be gained by questionnaire survey. Collation of fragmentary data is not possible. This suggests that the national mapping of flood hazard zones is unlikely to be successful unless there is detailed investigation of hazard in particular situations. Such investigations require a methodology not based on questionnaire survey.

(iii) Physical models of flooding in lowland floodplains can operate from basic topographic and hydrologic data. Photogrammetric techniques would allow the data to be collected relatively easily. Such models could identify the areas covered by floods of specific return intervals with a high degree of accuracy.

At this point having demonstrated that the protection works have a significant effect on the incidence of flooding on this floodplain, but that flood hazard remains considerable, it is logical to consider whether the flood potential has altered due to the changes in flood hazard. This question must be answered before any attempt to analyse the financial impact of flooding can be made.

CHAPTER III

The Assessment of Changes in Flood Damage Potential

3.1 Introduction

The object of this Chapter is to determine whether or not there has been a change in land use in the study area due to the introduction of protection works. The need to determine this stems from three sources:

(i) A partial objective of this dissertation is to determine the effects of the introduction of protection works. These may be considered to fall within three categories, namely: physical, cultural and economic effects of protection. A change in land use is likely to be the major cultural effect of protection.

(ii) The protection works have been shown to cause significant changes in the flood pattern. If the choice of land use prior to protection was constrained by flood hazard, and if the farmer faced with a changed flood hazard reacts to this in a rational economic manner, then a land use change might be expected.

(iii) If an accurate assessment of the economic impact of protection is to be made, it is necessary to determine the extent to which protection-induced land use changes have occurred.

The Chapter is divided into three sections. The first, a brief introductory section, indicates the importance of flood damage potential and reviews the traditional explanations of growth in floodplain occupance. A second section examines those theoretical and empirical studies concerned with investigations of rural land use change. These studies are used to formulate the methodology for work on the Nith. The last section discusses the methods, fieldwork and results of the Nith Study.

3.2 Flood Damage Potential[1]

In recent years an upward trend in mean annual flood damage has been observed (Holmes, 1961). Three explanations of this trend have been suggested. Firstly, the frequency with which flooding occurs may have increased. Secondly, the efficiency of flood reporting may have improved, thus apparent increases in the frequency of flooding would be detected in the collation of flood damage information by central authorities. Thirdly, the flood damage potential may be rising so that progressively larger losses may be caused by floods of much the same magnitude. These three explanations are to some extent interrelated, they may occur in combination and their effects are cumulative. In the Nith, it seems possible that the changes in the flood pattern caused by protection may have induced changes in flood potential.

[1] The term flood damage potential, damage potential and flood potential are found in the literature. The author accepts these as synonymous within this work.

Growth in flood damage potential is due to increasing amounts of investment in floodplain areas. When, why and to what extent this growth takes place are questions that, in the United Kingdom at least, remain unanswered. The consequence of such growth is, however, clear. When a flood occurs, as inevitably it will, the costs of flood damage are greater than they would have been if investment in the floodplain had been less. Furthermore, in many cases, especially in the urban, industrial and residential sectors, the investment is in houses, factories and other structures. These can increase the physical intensity of the flood by restricting the passage of water over the natural floodplain causing increases in flood depth, extent and velocity. In conditions of rising flood potential, therefore, the concept of flood damage as a natural tax on floodplain users as suggested by Renshaw (1961) may be more accurately considered as a graduated tax. In addition to the direct increases in loss that arise from increased flood damage potential comes further loss from the raised severity of the flood. Furthermore, these increases in the magnitude of the resulting losses focus attention on the flood problem in an area with a resulting improvement in the reporting of flood losses. Clearly, the relationship between raised flood damage potential and increased flood loss is complex.

The importance of possible increases in flood damage potential was first recognised by White in the United States. As early as 1937, White suggested that change in flood damage potential might affect the accuracy of flood loss reduction benefit calculations.

He stated then that this was a topic of some importance that required research. The growing belief that the reduction in flood frequency through structural protection (mainly at the expense of central government) causes possibly unwarranted increases in the intensity of floodplain use, has stimulated a number of studies which investigate[1] non-structural alternatives for flood damage alleviation.

Work by members of the Chicago School and more recently by a few British research workers has started to throw light on these problems. However, in general the emphasis has been placed on urban flood situations and little effort has been devoted to an examination of changes in rural floodplain occupance. White (1964) states that:

> "Change is less marked in the agricultural use of land and indeed there is some doubt as to whether or not such use generally is changing in the directions anticipated in the watershed plans."

Such questions are reiterated by Daugherty (1965; 1966).

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[1]Murphy (1958); Shaeffer (1960); Renshaw, Roder, Burton and Kates (1961) in the United States, and Harding (1972); Harding and Parker (1973) and Porter (1972) in the U.K.

3.3 Theoretical and Methodological Considerations

It is now necessary to examine the literature that is relevant to rural investigations of damage potential in order to consider firstly, the theoretical basis to the problem and, secondly, the successes and failures of the methods that have been applied in these studies. The results of these studies are critical in the formulation of the Nith methodology.

The work by Burton (1962) is the only attempt to argue at depth the theoretical relationships that, should at least, exist between the frequency of flooding and the intensity of land use. Two major points arise from Burton's considerations. Firstly, that in general floodplain users conform to the law of comparative advantage and, secondly, that land use intensity is not directly related to flood frequency but is modified by the actions of other variables such as floodplain width and slope.

Comparative advantage indicates that the profits made in flood free years must be sufficient to cover the costs incurred by periodic flooding. If this were not the case, the situation could not continue indefinitely. Either the profit margin would have to be increased or the losses be reduced. In the competitive British agricultural market, the farming system is unlikely to be far from optimum and, therefore, loss is the factor that can be most readily manipulated by the farmer. Since individual private protection is extremely costly and unusual, the real factor manipulated by the farmer to reduce his losses is the intensity of the investment. The possibility does remain that a different use at the same intensity of investment may allow emergency measures to be taken to avoid damage but such alterations are difficult to conceive of in an agricultural context. The difference between profits and losses, including loss by flood, forms the upper limit to land use intensity (assuming flood loss increases with land use intensity). The lower limit, at least in theory[1], is the lowest level of gross profits from turnover that can sustain the farm enterprise.

The intensity of use of floodplain land does not depend solely upon flood frequency. Issues of quality, quantity and demand for floodplain land in relation to the availability of adjoining land are also important. A farmer having all his land in the floodplain will have a more limited choice of use in comparison to a farmer whose farm embraces non-floodplain areas. Few farms in the study area embrace land on and off the floodplain. However, a questionnaire survey[2]

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[1] In practice many other factors may influence this lower threshold. For instance, the retention of land as a capital investment at times of rapid rise in land values.

[2] This survey involved all farmers in the study area. The interviews were unstructured, i.e. the questions were put to the farmers in an informal manner. The sequence of questioning thus differed from farmer to farmer. Some of the results of this survey are used to clarify theoretical aspects and to relate them to the study area. Questionnaire results are summarised in Appendix 2.

indicated that the majority, nearly 80 percent of the farmers have a second farm completely off the floodplain or run the enterprise jointly with other 'family held' farms off the floodplain. The resulting figures for tenure type were compared (see Appendix 3) with the figures for single and multiple holding farms in South Scotland using distribution free chi-square analysis (Quenouille, 1959). The chi-square value of 48.02 is significant at 99 percent rejecting the hypothesis that tenure in the Nith floodplain does not differ significantly from tenure in South Scotland. The comparison figures were obtained by personal communication with members of the statistics branch of DAFS. It is clear that because data could not be obtained for levels of aggregation below that of South Scotland these results must be treated with extreme caution. However, it does indicate a possibly rewarding research area in that the land use changes deduced from theoretical considerations may not in fact occur to the expected extent.

Variations in the site and tenure characteristics of the area mean that the inverse relationship between the frequency of flooding and the intensity of land use postulated by Burton will also vary. Burton generalises flood return intervals into three classes and relates the flood hazard at these classes to the attitudes held by the farm managerial staff. This is illustrated in Table 3.1 below.

Table 3.1 Relationship between flood frequency and farm managerial attitude. After Burton (1962)

Frequency Class	Return Interval (years)	Attitude
High	1-2	Careful analysis, choice of crops and attention to seasonality.
Intermediate	5-6	Decreasing attention to flood risk.
Low	7+	Flood risk is of little or no significance. Occupied by other managerial decisions.

It is useful to examine these relationships in the light of the changes in flood frequency[1] that have been found in the Nith floodplain. The recurrence interval of flooding that would have been experienced without protection is 1.28 years. Under Burton's classification the Nith valley would be designated a high frequency flood area. With protection, the number of floods falls and the return interval increases to 5.75 years placing the floodplain in the "intermediate" category. This suggests significant residual

[1] It is appreciated that Burton's return intervals are doubtless general measures based on flood frequency analysis, whilst these measures are based on actual and hypothetical flood experience. General frequency assessments will be dealt with at a later stage in this work.

hazard and therefore the farmer is not released from the hazard constraint that has governed his choice of land use. Changes in land use in the Nith may thus be less significant than expected. However, the results of questionnaire survey (Appendix 2) place the floodplain in the "low" frequency category on the basis of managerial attitude. When the question was posed: "To what extent do you take the possibility of flooding into account when formulating farm policy?", only three farmers considered that flood risk merited inclusion in the assessment of overall farm policy. This assessment, made by the majority of the farmers in the area, that flood risk was low and not important in policy formulation, may be explained by the farmers' perception and assessment of seasonality. All of the farmers identified seasonality as an important characteristic of flooding in agricultural areas. 71 percent of the farmers interviewed, correctly identified the seasons of minimum hazard. (Figure 3.1 shows the mean and standard deviation of the peak flows in each month for the Friars Carse record. The peak flows in the period from August to January inclusive are significantly higher than those in the remainder of the year). In the Nith only one flood in 23 years of protection has occurred in summer. The remainder were autumn or winter floods which happended after the main part of harvesting had been completed and before any large amount of investment had been made in the following years crops.

It may be that the farmer identifies the hazard through the frequency of floods that significantly damage the farm enterprise and not from the frequency of all floods. This possibility is borne

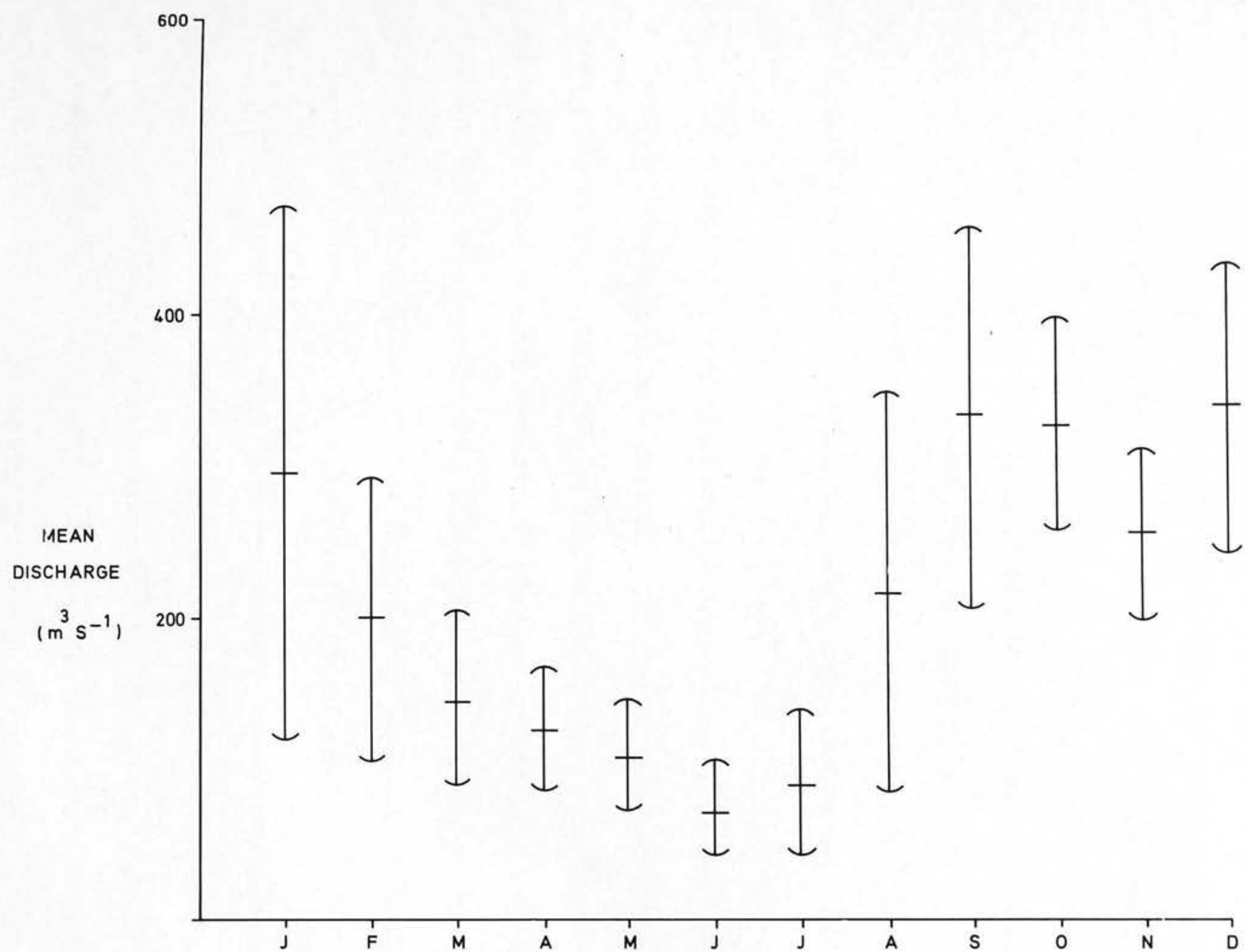

FIGURE 3.1 MEANS AND STANDARD DEVIATIONS OF THE MONTHLY PEAK DISCHARGES AT FRIARS CARSE.

out to some extent by the farmers' assessment of the frequency of flooding with protection. 43 percent of farmers interviewed identified the flood frequency of 10 to 15 years. 29 percent correctly identified the 5 to 10 year frequency class whilst the remainder identified frequency classes above 15 years. It has been noted that on Burton's classification the Nith has been reduced from a high risk to an intermediate risk area by protection. On the basis of the farmers' attitudes and the influence of seasonality, however, the Nith can be viewed as a low risk area. Therefore, the area might be expected to change from one where crop choice was constrained by flood hazard to one where crop choice depended on market circumstances.

It is useful to examine studies which have attempted to identify protection induced land use change. In the period from 1959 to 1972 three studies were conducted by the United States Department of Agriculture that sought to identify whether or not land use changes resulted from flood protection in rural areas[1]. All of these studies had strong methodological rather than theoretical orientation.

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[1]These papers and a number of papers discussed in later Chapters were received by personal communication with Dr. Mel Cotner, Head of the Economic Research Service of the Natural Resources Economics Division in the USDA. I am grateful to Dr. Cotner for the papers and for his comments on the papers and on my own work.

Cook (1965) examined three pairs of watersheds in the Upper Washita River Basin in Oklahoma. Each pair consisted of one protected and oneunprotected watershed. Data concerning changes in the intensity of land use were collected by interviewing farm operators in each watershed area. The results were inconclusive. They indicated that fewer changes took place than were anticipated. In two pairs of watersheds changes in use were tentatively identified whilst no evidence of change could be found in the third pair. Three factors may be responsible for the inconclusive results. The first is that the method of data collection may be inappropriate. The identification of land use changes by interviewing the farmer may be less preferable to data collected by observation. Errors due to inaccurate reporting or from statements of intent to change land use that were not acted upon can be envisaged. Theiler (1969) has in fact demonstrated that farmers may state their intention to change land use in order to facilitate the provision of central funding for a flood control project. The second factor is that the comparison of two watersheds always introduces the possibility that different management opportunities and environment may exist. In effect, the watersheds may not be comparable. Finally, the flood areas in the watersheds were already intensively used. The expected changes in land use, though they were rational and should have been noticeable in the survey, may not have been of sufficient magnitude to induce the farmer to make a change in his farming practice.

In 1967, Sloggett and Cook examined 11 watersheds in Oklahoma. Changes in land use were identified from previous land use inventories. This study did not suffer from the data collection difficulties of Cook's (1965) work discussed above, as the data were determined from field observations using a stratified random sampling procedure. Changes in land use over a 2 year period were presented but on testing were found to be insignificant. Again, the inconclusiveness of this study must be questioned. One possibility is that the spread of sites was too great. It is likely that the research workers were examining combined data derived from several economic environments in which the managers were faced with different sets of alternative courses of action. In addition, the time period over which the analysis was carried out was short. A long time period must elapse before significant proportions of a population adopt new ideas. This point will be discussed further in Section 3.4 below.

In the latest study by Sloggett (1970) attempts were made to gain positive results by expanding the study area to 56 watersheds covering parts of 8 states[1]. Once again a short, 2 year time period was used. No changes in land use were identified. Clearly this type of research programme fails due to the same inadequacies that have been discussed already, namely, the use of a short time period

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[1]New Mexico, Colorado, Nebraska, Oklahoma, Texas, Missouri, Arkansas and Louisiana.

and, in this case, entirely different farm types and economic regions. The progressive reduction in the success of these 3 studies is, it is suggested, due to increasing the range of study locations which continually introduces further variability into an already complex subject. All of these methodological deficiencies must be borne in mind in formulating a tool to study land use changes in the Nith area.

3.4 Nith Methodology

One of the most important factors in the adoption of new ideas and practices is time. Lack of attention to this factor may explain some of the difficulties experienced in the research projects discussed above. Ryan (1948) has shown that the rate at which a population accepts innovation varies with time in the manner shown in Figure 3.2. The adoption process itself is complex, depending upon such things as the risk involved, observations of the density of adoption in surrounding areas and the complexity of the innovation itself. Work by Wilkening (1953) and Limberger (1960) amongst others gives a guide to the adoption process.

Adoption rate varies with time as an S curve. Initially the rate is extremely high. A very small percentage of any population will adopt new ideas for the sake of novelty. There then follows a period of very slow adoption. After 6 years a total of only 15 percent of the population may have accepted the new process, but this is a sufficient proportion to allow others to observe easily the effects of adoption. In succeeding years, the innovation spreads rapidly

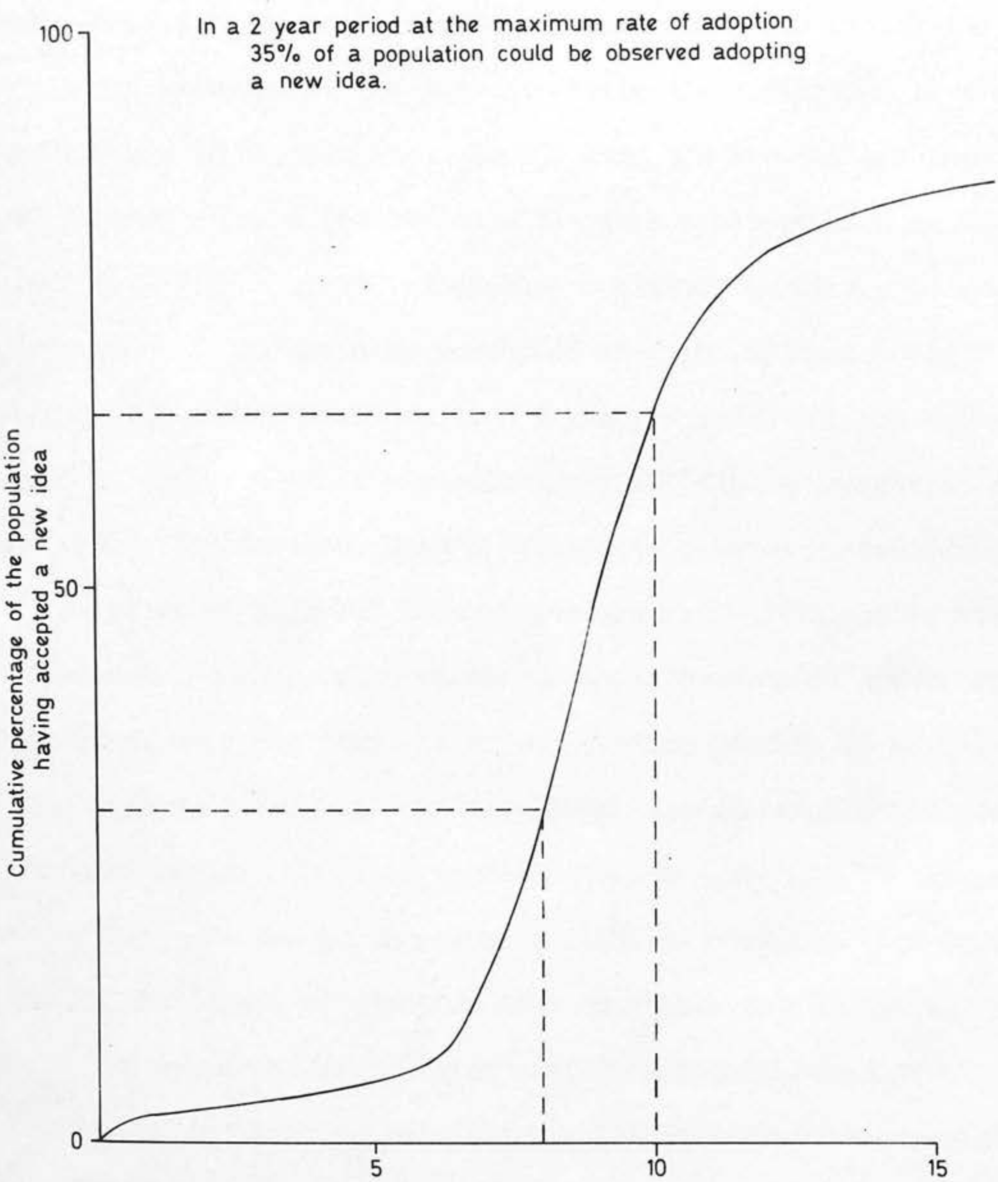


FIGURE 3.2 THE RELATIONSHIP BETWEEN ADOPTION RATE AND TIME. AFTER RYAN (1948).

throughout the community until by the twelfth year after its introduction some 80 percent of the population have accepted the change. Thereafter the rate of adoption declines and it is unlikely that the whole population will ever change. It is clear that a period of 2 to 3 years is not sufficient to allow enough individuals to adopt with the result that identification of change in the population as a whole is impossible. From Figure 3.2 one can see that a maximum of 35 percent of a population will adopt a new process in a 2 year period. If one third of the population is likely to assess an innovation as potentially worthy of adoption by them, only 1 observation in 10 will indicate change in a 2 year period. At other times as little as 5 percent of a population will adopt a process in a 2 year period. In addition, Ryan's relationship between adoption and time does not refer to rural communities who are traditionally expected to be slower and more conservative in their acceptance of new ideas. Assuming, however, that the rural adoption process is not slower than that envisaged in Ryan's model, 90 percent adoption would still take 15 to 18 years. This is several times longer than the elapse time allowed for in the North American studies cited above. In the Nith study, the length of adoption time was taken into account.

An extension of the time period over which the identification of changes in land use intensity is sought introduces a new problem; namely, increased probability that observed changes may be due to factors other than the protection works. A simple comparison of land use before protection with the land use existing some years later after protection is not adequate. Nor can a simple comparison of present land uses in similar protected and unprotected areas of the floodplain be considered satisfactory. What is required is that the changes in the land use in the protected area observed over a specified time period starting before the date of protection provision and continuing for several years after this date, must be compared with the changes in land use observed over the same time period in a similar unprotected control area. Essentially, one is seeking to compare two comparisons thus involving 4 land use surveys. The use of this method means that changes in land use due to such factors as variation in demand for crops and livestock with time will not invalidate the analysis.

The adoption time problem is contained by using a long time period. Changes in the study and control areas are examined over the same time interval. Time-related variables which may cause change, i.e. market fluctuations, fiscal policy changes, technological advances and changes in managerial skills and attitudes, should operate equally on both areas. Space-related variables such as market possibilities (it could be assumed that this is also distance constrained) altitude, slope, aspect, soil type, climate are controlled for by using as a comparison area, sites of low slope and neutral aspect that lie on the opposite side of the valley about 1 km west of the study area. Soils in both areas exhibit disturbed agricultural profiles (profiles changed by agricultural activities) having artificially controlled fertility. Officials of the Agricultural

Advisory Service classify both areas as mixed arable/dairy farming. Height differences between the areas is some 20 m. Both areas are equidistant to Dumfries, the main agricultural market centre. The author recognises that slight differences in the quality of the land in the two areas could be identified in terms of drainage and height, but would argue that these differences are of a lower magnitude, than those which could be detected at the same detail between 2 watersheds, a technique used in others studies, Sloggett (1970). A more important argument is that the two sites are not being directly compared only changes in the sites are being compared. Effectively then one is comparing changes from similar baselines.

The land use for the entire protected area was examined and the land use over 240 fields before and after protection was determined. Data deficiencies in either pre- or post-protection eras reduced the sample to 203 cases. In the comparison area 86 fields were examined. Manuscript maps[1] of the land use assessment prepared by Stamp, were used as the source of pre-protection data. The maps were in fact reduced negatives of originals which were lost by fire. Data for post-protection land use were determined by field observation.

The data, 578 items, 2 per field in the study and control areas, were placed in the following categories. It was hypothesised that

Crop	Code
Permanent pasture	1
Temporary pasture within crop cycle	2
Root crop	3
Cereal crop	4

[1]The author wishes to thank the map room staff on the National Library of Scotland for the very considerable help in locating these maps.

these categories formed a progression in flood proneness from permanent pasture to cereal crops. Permanent pasture being the crop least prone to flood damage and cereal crops being the most prone to damage. Support for the use of this progression comes from two sources. First, in the following Chapter damage estimates from a large number of samples covering several crops indicate that the hypothesis is valid. Second, cruder progressions can be found in the literature and are in the same direction as those used here. For example, in Theiler's work in 1969 two categories were recognised, pasture land or crop land, the expected change being from pasture to cropped land.

3.5 Results

The land use data for the study area and for the control area are shown in Tables A3.1 and A3.2 respectively, in Appendix 3. The change in land use in each field is noted as a shift to the left, to the right or no change. The degree of shift was also calculated. A cereal crop occupying a site previously permanently pastured would be a shift of 3 units to the right.

Figure 3.3 shows frequency histograms of the 4 crop categories examined for under the 4 situations considered which were:

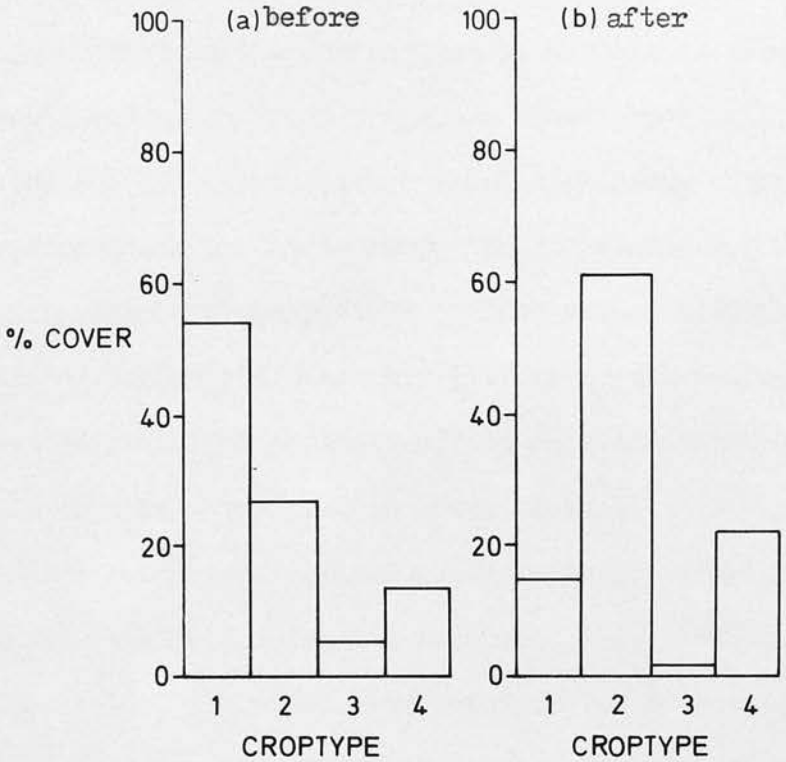
(a) The study area before protection.

(b) The study area after protection.

(c) The control area before protection.

(d) The control area after protection.

THE STUDY AREA.



THE CONTROL AREA.

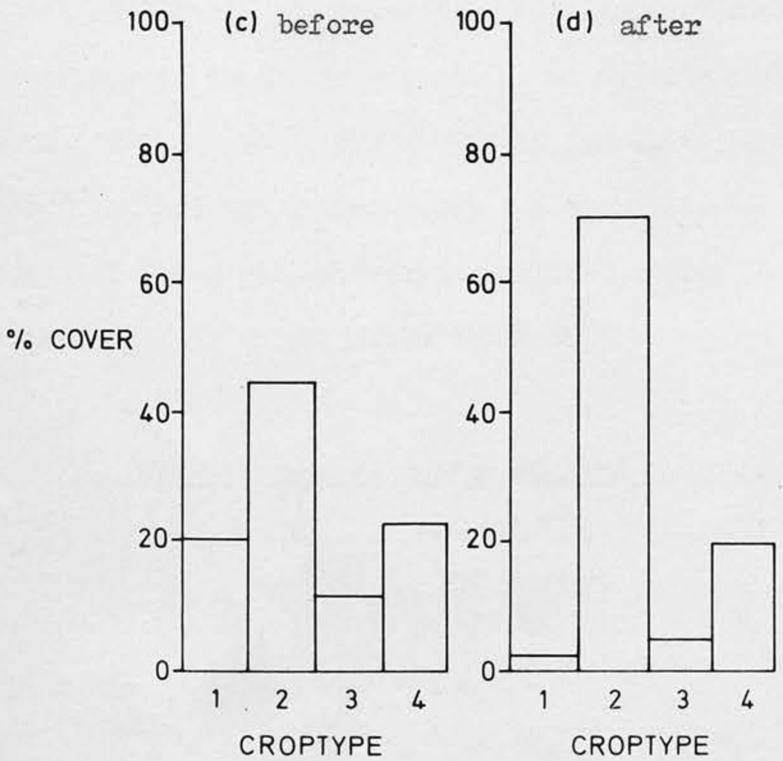


FIGURE 3.3 CROPPING PATTERNS IN THE STUDY AND CONTROL AREAS BEFORE AND AFTER PROTECTION. SEE TEXT FOR EXPLANATION.

The similarity in (b), (c) and (d) is noticeable. In each case temporary grass is the dominant crop, cereals is sub-dominant and permanent pasture or root crops are least important. Figure 3.3 (b), (c) and (d) represent low flood risk areas either due to their natural position or due to protection. Figure 3.3 (a) is the high risk area and here the pattern of land use is different. Permanent pasture dominates and temporary pasture is sub-dominant. A subjective graphical analysis of the data indicates change in land use towards the form found in low risk areas.

More formal statistical analysis is preferable. The data can be readily analysed using chi square. This analysis follows the hypothesis that the attributes noted in two groups differ only due to chance and that the two groups are in reality from the same population. The data are then examined to determine the probability of chance explaining the deviations of observed from expected values. This analysis is described and discussed in Udny Yule (1950) and Snedecor (1967). Table 3.2 shows the aggregated data on directions of change in land use in the study and control areas. To produce a statement of the expected frequencies the numbers in the control area were raised by 2.36 to provide a total of 203. Chi square analysis

Table 3.2 Frequency and direction of land use change in the study and control areas

	Left	No change	Right	Total
Study area	31	59	113	203
Control area	21	32	33	86
Total	52	91	146	289

tested the hypothesis that there was no difference in the changes in the study and control areas. From Chi square tables a value of 9.21 would indicate rejection at the .01 level. A Chi square value of 26.40 was calculated and the hypothesis was therefore rejected. Differential land use change has occurred and the difference is attributed to protection.

The frequency, direction and degree of shift in land use is shown in Table 3.3. To reject the same null hypothesis as used above a Chi square value of 16.8 is required, the Chi square value calculated in this case was 60.48. Once again the null hypothesis is rejected at the 0.01 level indicating that changes in land use due to protection have occurred.

Table 3.3 Frequency, direction and degree of shift in land use in the study and control areas

	Shift to left			No change	Shift to right			Total
	3	2	1	0	1	2	3	
Study area	5	16	10	59	78	19	16	203
Control area	2	12	7	32	20	11	2	86
Total	7	28	17	91	98	30	18	289

3.6 Conclusions

The land use changes expected from the changes in flood hazard caused by the provision of protection works and indicated by theoretical work of Burton have been found. Changes in flood potential do occur in agricultural areas in the United Kingdom. It is clear that this type of work needs to be repeated in other areas having both the same and a different form of agriculture before any general statement can be made. In economic terms, it would be important to know the rate at which this land use change took place. It is a failure of this methodology that these time relationships are left unknown. To obtain this information, it would be necessary periodically to determine the land use on a sample protected site and on a control site. Such monitoring would start before the construction of protection works and thereafter quinquenially for a minimum of 20 years. It is the author's opinion that such long term survey work, without which the theoretically advanced models of Brown, Contini and McGuire (1972) cannot be fully used, should be undertaken by government-sponsored research.

A difference between the type of occupancy in the Nith floodplain and in the rest of South Scotland has been noted. The author believes that this type of occupancy has developed as a form of economic defence against flooding or that flooding may select against occupants of single farm holdings. An examination of the mechanics of the protection that such types of occupancy exhibit may be an important subject for future research. In the United States the Inland Revenue Service allows a tax deduction on the basis of flood damage assessment for several years after the damage occurs. It would be of interest to test the hypothesis that when taxed as a single firm, multiple farms introduce a buffer effect by deducting damage from tax over the whole business thus protecting the "profit" of the flood free farm. If this happens it would be another form of protection provision at the cost of central government.

CHAPTER IV

Flood Loss Assessment

4.1. Introduction

The assessment of flood loss is basic to any study concerned in part with investigating the financial implications of flooding. As will be shown it may be argued that it is this question that has been inadequately addressed in the past and this chapter attempts to throw light upon the problems inherent in flood loss assessment. It is important to consider the existing methods of assessment in order to identify the weaknesses and advantages of these systems.

Two main methods of loss assessment may be identified:

(i) retrospective loss assessment, and,

(ii) potential loss assessment.

Retrospective loss assessment involves visiting the flooded areas as soon as is practicable after the flood event and assessing the losses caused by the flood. Potential loss assessment involves attempting to assess the flood losses that would occur if an area were to be flooded at some time in the future. It has been suggested by Harding and Porter (1970) that the Universities should accept responsibility for potential loss assessment whilst the River Authority (or presumably their regional water authority equivalents within the new structure of the water industry) should be responsible for retrospective assessment. However, both of these methods of loss assessment are not without problems which can be conveniently considered under four headings:

(i) Totality.

(ii) Assessor skill.

(iii) Costing.

(iv) Communality.

Consider firstly the group of questions that surround the problem of totality, a problem which is most severe in the case of potential loss assessment. Are the losses assumed to be total or is a more complex situation envisaged in which losses are variable in extent? If the latter is the case then one must consider the basis on which loss is to be calculated for future floods. Even in retrospective assessment it can be envisaged that difficulty might occur in attempting to assess loss. If it is assumed that there is total loss then the justification and implications of such an assumption must be considered. Assumptions of totality mean that the estimates of loss will be exaggerated.

When one considers the diversity that occurs in the types of articles that are damaged by flooding it becomes immediately apparent that the task of assessing losses is complex. Clearly then the assessment requires expertise on the part of the assessor. Not all assessors have such expertise. On many occasions it is the local newspaper or other mass media reporters who make the estimates of flood loss. Admittedly the information may be a digest of interviews with the managers of the damaged firms but as shall be expanded on later these people are personally involved and their estimates are unlikely to be objective. Yet recently learned journals have contained contributions in which flood loss estimates have been derived from local newspapers. It is important that this problem is recognised by all users of flood loss and flood damage data.

The costing problem involves the choice and measurement of those costs used in the assessment. Is the assessor to attempt to evaluate indirect costs such as loss in production or loss of opportunity? To what extent must intangible costs be considered? Are the possible alternative uses of the damaged product to be considered in the assessment? Here is a costing problem that is very closely related to the problem of totality. A crop may be totally destroyed in relation to the market for which it was first envisaged but might well be marketable, albeit at a low price, in an alternative role. If machinery or implements are damaged by the flood is a replacement cost used and if so is this based upon the cost of a new machine of the same type, upon the cost of a used machine of the same type or upon the cost of a new and modern machine that fulfills the same function in a more efficient manner? Data on flood losses should include a statement of the assumptions made and the costing procedures employed in the collection of the data.

Probably the most serious questions arise from the fact that many estimates are obtained by direct interview with the people whose property and possessions have been damaged or destroyed by the flood. These people have a high degree of self-interest in the results of the analysis. It is natural that they will wish to draw attention to the plight that they find themselves in, and it seems likely that they will attempt to achieve this end by exaggerating their accounts and estimates of the losses suffered. This is only a part of the problem of communality that is encountered in many natural resource situations. The goods, in the case under consideration the damaged articles and the responsibility for the prevention of distress suffered due to flood loss, are often not owned by one person but by a number of people, or by the public. When this is the case the responsibility for the payment of the whole or part of the losses may lie with central government or local authorities. Therefore the onus lies on the damaged party to obtain "beneficial" estimates of damage.

Finally, there are the further problems involved in the estimation of future flood losses. Two situations can be envisaged. The first in which flood losses have been evaluated after previous floods in the area and the second in which flood losses are being estimated in a site at which no flood has occurred in the recent past and for which flood loss information is not available. In the former case the problems discussed above still apply to the retrospective estimate but in its application to future losses further assumptions must be made: namely, that the price structure operating in the floodplain remains essentially unchanged and that the spatial distribution of capital invested in the floodplain remains homogeneous. In the latter case, the estimate of potential flood loss must be made on the basis of flood loss experience from other areas. All of the problems of retrospective assessment and of the application of the information contained in that assessment to future floods remain. In addition new problems arise in the application of the "guidance area" estimate to the site of the potential loss assessment. Of these problems the most important is that of defining the areas flooded by floods of specific magnitudes. But more academic problems relating to the similarity of the enterprises and therefore financial inputs also exist. Potential loss assessments made without detailed information from floods in the same area must be considered crude.

It is the opinion of the author that a number of problems that arise in the assessment of the impact of flooding stem from imprecise terminology and a lack of appreciation of the differences that exist between the physical and the monetary effects of flooding. The adoption of the term <u>damage</u> to express the relative financial loss, effectively the physical impact, and the term <u>loss</u> to express absolute financial loss would reduce terminological confusion. This system of nomenclature has been adopted in this thesis. The distinction between these two terms may be made clear through the use of a simile. Consider two plates which fall and break. Here damage, loss in utility, is almost total in both cases. However, the value of one plate may be several times that of the other plate. Thus it is possible for the damage values of two events to be very similar whilst the loss values might be very different. If field surveys are restricted to damage assessment only then the problems of communality and costing are reduced. Since monetary estimates are not required there is a reduction in the likelihood of producing estimates that have been expanded due to communality. Since the choice of the costing procedures employed is in the hands of the assessor, the chosen procedures may be uniformly applied throughout the survey area and may be noted with the data to improve its "quality" for comparative and aggregative purposes.

4.2 The Structure of the Investigation

In the Nith floodplain the land use is known in some detail and therefore the capital invested in the floodplain at various times of the year can be calculated. In addition the areas covered by floods of various return intervals can be determined through the use of the model discussed in Chapter II. However, these two sources of data can be combined to determine the losses caused by particular floods only if the concept of totality can be demonstrated to be true. The first task, therefore, is to test the hypothesis that damage to flooded crops is total. It is clear that loss is not a suitable measure for this purpose as it would subsequently have to be related to the potential loss if deviations from totality are to be identified. Such a relationship is effectively a measure of damage. The proposed method is to conduct a random survey of flooded farms and within these farms to examine a number of randomly selected flooded fields. At each of these sites the damage can be estimated and in those cases where the crop was subsequently sold the estimate can be checked by reference to the price obtained and to the selling price of similar undamaged produce. It will then be possible to examine these data and state the extent to which the concept of totality exists in reality.

If the hypothesis is rejected then it will be necessary to attempt to determine whether the range of damage suffered typifies all crops or whether there are differences in the damage levels suffered by different crops. If the range of damages can be shown to be similar in all crops then it would only be necessary to construct one general relationship between flood characteristic and damage and to determine a costing based upon an average of the costs of the various crops found in the floodplain and weighted by their areal representation to provide a basis for calculating loss. The damage levels in different crops can be investigated by noting the crop type in each field studied during the random survey of flood damage discussed above. The data can then be subdivided on the basis of crop type and the resulting means compared using an appropriate statistical technique based on the characteristics of the two groups of damage estimates.

Should crops be demonstrated to be differentially damaged it becomes important to explore the relationships between damage and characteristics of the crop and flood. The method used in this study was to determine the characteristics of the crop and flood at each of the randomly chosen sites. The characteristics were collected by observation, measurement and interview. Data subdivision by flood characteristics groups the damage estimates and allows general relationships to be established which can be statistically tested. However, subdivision by crop <u>and</u> by flood characteristics will yield observation numbers that are likely to be too low for the type of analysis outlined above to be applied successfully and so to explore these relationships within crop type correlation analysis is used.

In an attempt to clarify this complex and intercorrelated matrix of data multivariate techniques are finally applied.

4.3 Site Choice, Characteristics and the Sampled Units

There was no explicit choice of site. The first floods that occurred on the lower valley floodplains of major rivers and which caused damage to crops were chosen for study. These areas were selected for the following reasons. Firstly, the majority of high capital input farms such as those found on the Nith are located in the lower valleys. Secondly, it was desired to reduce site variability as this was in essence a pilot investigation. Thirdly, the floods in the lower valley areas were given better publicity and were therefore easier to find than obscure flood events in remoter areas.

The number of sites was limited by the time required to identify and visit them and collect the appropriate data. In this instance the total number of cases was 200, of which 137 were selected for full analysis. Most of these are located in N.E. Scotland where severe floods in 1970 afforded an excellent opportunity for obtaining field data of the type discussed earlier in this Chapter. The floods covered wide areas in Aberdeenshire, Banffshire, Morey, Nairn and Invernessshire. The floodplains of the rivers Spey, Lossie, Findhorn and Nairn together with tributaries of these rivers were the most severely affected areas that were of interest in this study. The location of these rivers and their tributaries and the sites of the principal[1] farms used in the investigation are shown in fig. 4.1. The Spey at this time was estimated to have reached a stage of more than one metre above the highest previously recorded (Moir, 1970). The Lossie changed its course and in the process destroyed roads, buildings and a gauging station. It is perhaps worthy of comment that although in this study the emphasis is placed upon crop damage it is appreciated that in the overall picture of agricultural damage, structural and equipment damage is also important. In these floods in the north-east there was considerable evidence of non crop damage. Historically agricultural flooding has long been important in the area and this is described by Lauder (1830) and Nairne (1895). Although the rivers Spey, Lossie, Findhorn and Nairn have been named as being responsible for the flooding, the direct cause of inundation in many cases was a feeder stream or large drainage channel such as the Spiny Canal which caused considerable damage at its confluence with the River Lossie.

Twenty-two principal farms were visited and in each of these a number of damaged fields were examined. The farms were chosen at random from those known to be severely flooded by each river. The procedure used was to list the farms known to be flooded and then to rank them using random number tables. Farms were visited sequentially

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[1] The principal farm is the farm at which the flood damage took place. The methods used in the data collection required that a number of farms adjoining each principal farm were also visited to check the data.

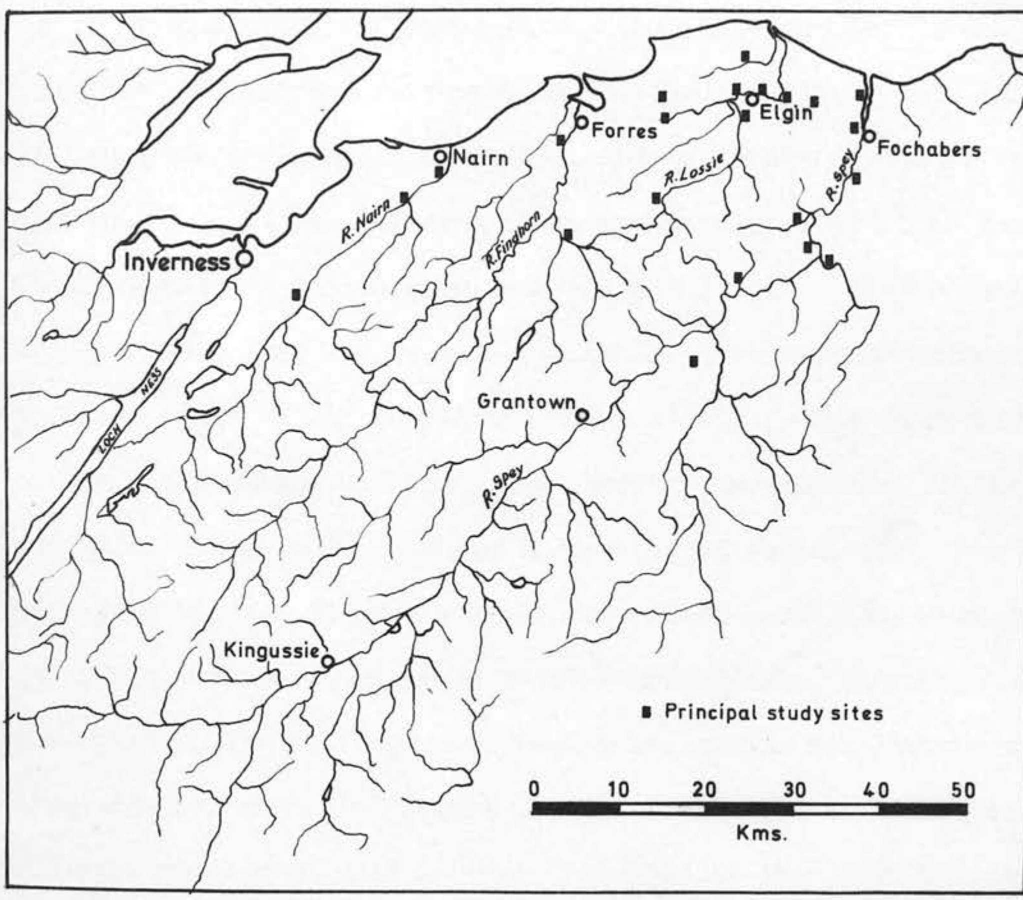

FIGURE 4.1 LOCATION OF PRINCIPAL SITES STUDIED FOLLOWING THE 1970 FLOODS IN THE NORTH EAST OF SCOTLAND.

down this randomly ranked list until time made it impossible to collect further data. There was therefore stratification by river and as will be noted later it may be that further stratification was required to derive an adequate sample of floods at the flood edge. In each farm about half of the fields flooded were selected at random for detailed examination.

The individual unit chosen was the field not the farm. The rejection of the farm in favour of the field unit was made in order to focus the investigation at the point of impact of the flood, the floodplain. It was believed that the assessment of flood damage would be more objective when made at this level. If the whole farm is used then other influences such as size, tenure and management policies might unduly complicate the analysis. The major advantages of the field unit are firstly that accurate measurement of the flood variables can be made. There is no loss of information through averaging results to give a whole farm flood variable. Secondly, the field unit is superior to point sampling as an interview unit and thirdly, the data are more easily stored for handling purposes. Areas smaller than fields were not chosen because the field is the smallest management unit in most farms and is therefore the area for which data are most readily available.

4.4 The Choice of Variables

The first most basic step in the collection of data for analysis is to choose the variables on which observations will be made. It is at this stage that a balance must be sought between what is feasible under field conditions and what is desirable in theory. The second step is to examine the individual variables chosen for study and to consider how observations on these variables may be collected. The third step is to outline the limitations of the method of collection and to discuss the measures taken in the field to contain these limitations. This section attempts to achieve these ends.

The variables chosen for collection can be considered as two main groups, firstly, the dependent variables and secondly, the independent or regressor variables. These latter variables may be further subdivided into three groups: those that define aspects of the crop, those that define aspects of the flood and those that define the location of the observations. This latter sub group has been used exclusively to subdivide the data. The variables used are shown in Table 4.1 in which the subdivisions of the independent variables are termed crop, flood and location variables.

Two dependent variables were studied, damage and loss. These will be discussed in more detail below but the broad distinction between the two terms remains that defined in section 4.1. The crop regressor variables chosen were crop type and crop age whilst the locational variables chosen were the river and the farm. Five regressor flood variables were chosen for study. These were the absolute depth of the floodwater, the proportion of the plant submerged, the duration of the flood, the sediment deposited by the floodwaters and the velocity of the floodwater.

Table 4.1 Variables used in the damage assessment study

Variable		
Damage	Dependent variables	
Loss		
Crop type	Regressor or independent variables	Crop variables
Crop age		
Absolute depth		Flood variables
Proportion submerged		
Duration		
Sediment deposit		
Velocity		
River		Locational variables
Farm		

The first dependent variable estimated was damage. This was assessed jointly by the author and by the manager of the damaged farm. Damage was measured as the estimated percentage reduction in the utility of the crop. For any crop intended for direct marketing this is synonymous with the estimated percentage reduction in the revenue from that crop. Such a measure has been used by the Economic Research Service, see for example Mallett (1962) and Daugherty (1966).

Clearly, such forms of estimation involve consideration of both the reduction in yield and changes in the quality of the end product. To some extent these data could be checked by relating the actual selling price of the crop to the price that undamaged produce attained at the end of the season. However, it should be re-emphasised that some crops, for example improved meadowland pasture, are not intended for direct cash sale and it is therefore not possible to check estimated damage by reference to its final selling price. Damage was therefore an estimate supported by follow-up studies on about 70 percent of the cases where the crop was finally sold.

In an effort to maintain objectivity in the field a key was devised for use during the damage assessments. The key is shown in fig. 4.2 and requires comment on three features in particular. Firstly, it is clear that this form of key can only be used in estimating the amount of direct damage to the crop. If the change in utility is to be correctly taken into account then one must distinguish between a crop that has an alternative use (for example a barley crop originally intended as a malting crop and still suitable for feed) and one that has no alternative use. Secondly, one must consider the importance of crop age as a determining factor in the final assessment of damage. Thirdly, one must consider the type of crop being examined and apply the key in a rational manner appropriate to the characteristics of particular crops. A general key is not applicable in its entirity to all crop types.

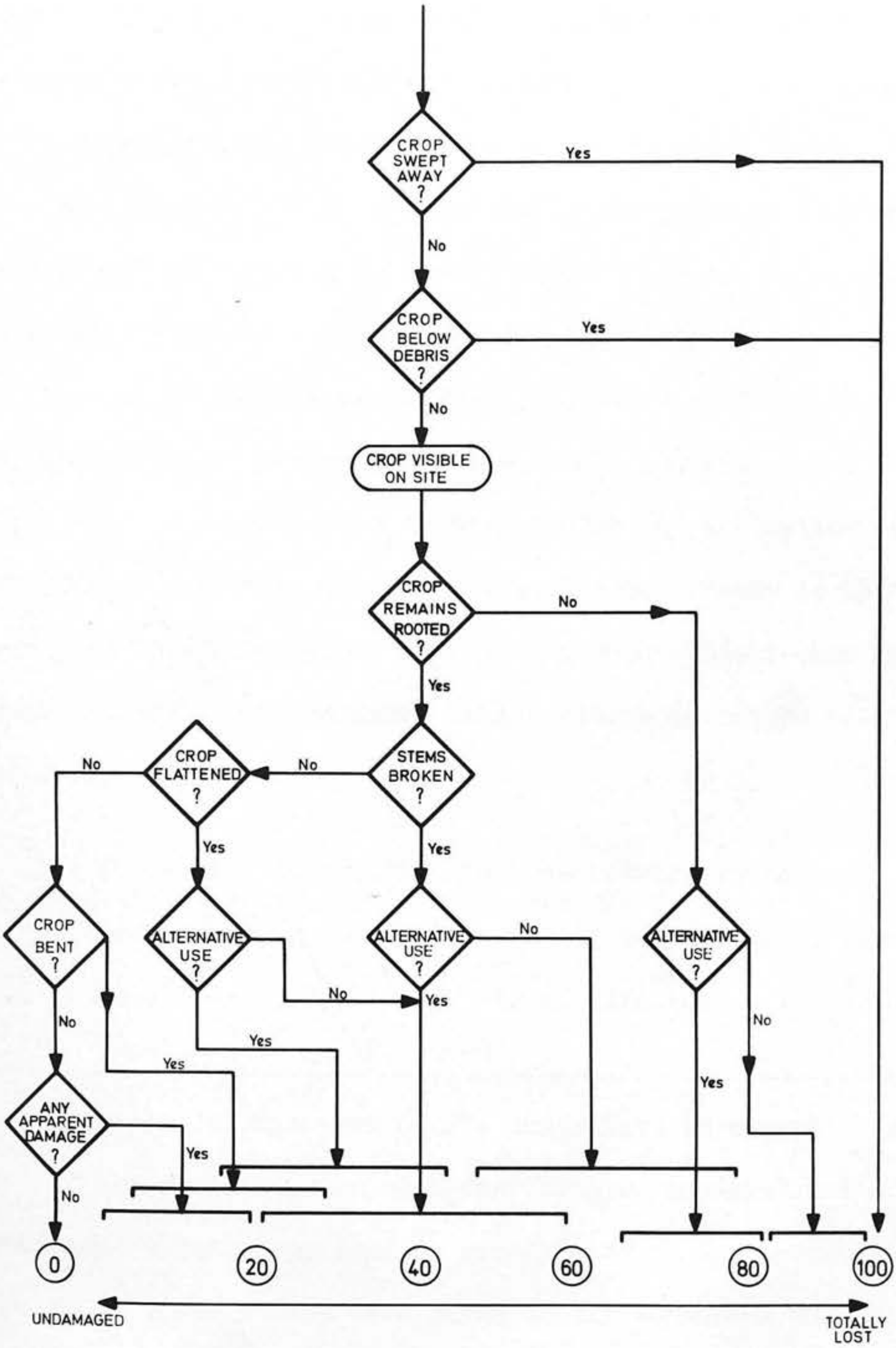

FIGURE 4.2 GENERAL KEY USED IN FLOOD DAMAGE ASSESSMENT.

The second dependent variable measured was loss. This was measured in pounds per acre[1] and is an estimate made by the farmer alone. The approximate value of this figure was checked by reference firstly to the damage category and secondly to the crop costings data published by the Farm Management Department of Aberdeen University (1970). Loss figures were not questioned further.

The crop type was determined either by personal observation or from information supplied by the farmer. In total ten crop types were examined but due to lack of sufficient data in certain categories only six crop types were individually analysed. The crops were classified only by general crop types such as wheat, barley etc.. In determining the crop type in this manner the assumption is made that a finer differentiation is not required. There is little real support for this assumption and this may be a subject that requires further research. Three areas of investigation can be identified immediately.

(i) Should differentiation be made between varieties?

(ii) Should spring and winter cereals be considered separately?

(iii) Should the possible effects of differences in cultural practices be investigated?

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[1] Where possible in this work metric units have been used. However, in all of the field studies with the farmers, imperial units were used as this terminology remains widely used in the agricultural community. These values were subsequently converted to metric units.

In this study differentiation stopped at the common crop level. There are two reasons for this. Firstly, there is some justification in suggesting that from both an academic and logistic point of view questions on differentiation might be better answered in a separate study refined by the knowledge of the problems encountered in this study. Secondly, time and opportunity limited the amount of information that could be collected. If the categories of crop type were subdivided it was likely that the number of cases in each new "crop type" would have become insufficient for satisfactory analysis. It is believed that the results obtained from this study support the crop categories chosen.

The second crop variable used was crop age. The method of determining this was greatly influenced by the decisions made concerning the crop type variable. The use of combined spring and winter cereal categories means that crops which are several months apart in time as measured say by elapsed time since planting may be at the same stage of development. This problem was avoided by the use of age categories related to developmental stage as shown in Table 4.2. In those cases where the crop remained to be examined the age was assessed by the author. If, however, the crop had been swept away or buried, the age category was determined by interview with the farmer. The determination of age on this basis placed more emphasis on management significance than on biological importance although this clearly remains of considerable significance. Thus the identification of crop age by the farmer caused little difficulty.

Table 4.2 Categorization of age by stage of development

Coding	Stage	Description
1	Pre-emergent	The crop has been planted but as yet the shoots have not emerged.
2	Emergent	Shoots have clearly penetrated the ground surface. Effect on undamaged field seen as a green haze.
3	Seedling	Beyond emergent stage but canopy is not yet closed.
4	Juvenile	Canopy closed but pre-ripening stage not yet attained.
5	Pre-ripening	The product (tuber, ear, etc) has formed but is not sufficiently ripened to be marketed (at least for its original purpose).
6	Mature	The crop is in all respects mature, it remains in the field for marginal further increases in quality and yield but more usually as a matter of managerial convenience.

The first flood variable examined was absolute depth. This was defined as the maximum depth of the floodwaters in centimetres. The measure was derived from flood marks and was verified by discussion with the farmers. Depth is the most commonly used field statistic concerning the attributes of floods which cause damage. It is without doubt a crude measure of a number of depth related parameters the measurement of which is more complex. For instance the duration of flooding at differing depths may well be a more important measure than depth alone. In studies in the United States both depth and duration have been measured but these have been separately related to damage (see for example White, 1964).

As the second flood variable a measure of depth in relation to the height of the crop was made in the belief that this might be of more biological significance than absolute depth. This is suggested by the work of Greenwood (1967) which indicates that plants may have the ability to translocate oxygen from their aerial parts to the root system, a critical ability during the essentially anaerobic conditions that exist during flooding and an ability that is likely to be seriously, indeed completely impaired by the submersion of the aerial parts. The measure of the proportion of the plant submerged was coded as indicated in Table 4.3.

A more relevant measure may be considered to be the submersion of critical parts of the plant. For instance in the case of a cereal crop the flag leaf or the ear. However, this measure was rejected due to the difficulties raised by the question of compatability in

Table 4.3 Coding used in relation to the percentage of crop submerged

Coding	Percentage Submersion (S) %
1	$0 < S \leqslant 10$
2	$10 < S \leqslant 30$
3	$30 < S \leqslant 50$
4	$50 < S \leqslant 70$
5	$70 < S \leqslant 90$
6	$S > 90$

the measure when applied to different crops. The potato for example has neither flag leaf or ear. One could to some extent avoid this problem by the use of dummy variables, that is a variable that will take a zero or one value only depending on whether a specific part is submerged. But such a measure still implies that the part exists to be flooded.

As was mentioned above duration is the other measure that has been commonly applied in flood studies. In the present work it was measured as hours of above ground flood duration. This measure can be accurately determined from the farmer who is usually sufficiently anxious about flooding to observe very carefully the behaviour of the river at the time that flooding is about to occur and who is equally anxious to examine in detail the damage to his crops as soon as the water has receded. In some cases anomalies in the duration data were apparent. If the doubts about the farmers' estimates of duration were confirmed by interviews with other observers in the area that case of data was not utilised in the analysis. It will be appreciated that although the time of onset of flooding tends to be uniform within localities the time at which a flood recedes is much more localised and this is not readily checked.

In this study the sediment remaining in the fields following deposition during the inundation was used as a measure of possible damage by sediment deposition. The sediment deposited was categorized as shown in Table 4.4 by reference to the largest particle sizes found on the site but also taking into account the possibility of floating debris amounting to a major deposit. It is unfortunate that no measure of the load carried by the floodwater could be made. It seems unlikely that the measure of deposit can be taken as an index or an indication of the value of load although this does not detract from the value of deposit itself as a damage linked variable. The measurement of the sediment variable could have been improved by determining the range or the proportions of the different sizes of sediment deposited. However, this would have been a very time consuming task which would have reduced the total number of cases examined without perhaps contributing a great deal of further information.

The final flood variable examined was velocity. Logically this is likely to be an important damage producing variable but none the less only one previous study could be found where its measurement had been attempted in relation to agricultural flood damage (Daugherty, 1963). Daugherty's work on damage factors for selected crops and pasture formed a part of the special study on

Table 4.4 Categorization of sediment deposits

Coding	Description	Size
1	No debris	not applicable
2	Floating debris	not applicable
3	Clays-Sands	0.002-2.0 mm[1]
4	Gravels	2.0 -20.0 mm[1]
5	Stones	> 20 mm

[1] Category three covers the range from clay to coarse sand in the USDA (1951) classification commonly used in the U.K. Category four covers the fine and medium gravel ranges in British Standards 1377 (1961). Particles in excess of 20 mm include coarse gravel, cobbles and stones as defined in the same British Standards document are included in Category five.

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flood damage to growing crops and pasture in the South Eastern United States carried out by the Resource Development Economics Division of the Economic Research Service. In this American study the respondents were asked to place the velocity of the water into one of the following categories:

(i) Backwater flooding.

(ii) Floodwater velocity of a rate considered insufficient to cause damage but which was not merely backwater.

(iii) Floodwater whose velocity is considered to be sufficient to cause damage.

These velocities were coded one, two and three respectively. The categorization of velocity through such a system means that the respondent is being asked to relate velocity to damage and thus the regressor variable is no longer independent of the dependent variable. This is an unacceptable violation of the independent nature of the variables required for the form of analysis applied in the American study. In the present study the farmers were asked to place the velocity in one of three categories, slow, intermediate and fast, coded one, two and three respectively. The questioning in relation to velocity and to damage were separated in order to reduce the influence of the responses on each other. No explicit connection between the velocity and the damage was made by the interviewer. The velocity figure that was obtained by the farmer was checked by reference to the estimates of the velocity of the flood made by other observers. If the estimates of the farmer deviated from those of the other observers that case of data was removed from the analysis.

The use of the form of velocity estimate describedabove introduces the problem that if the equations are to be useful the estimates of velocity must be related to some computable measure of floodwater velocity. It is interesting to note that Daugherty did not relate estimated velocity to any measure of real velocity. In a perfect situation it would be preferable to ask all farmers to relate these two velocities by cork and stopwatch trials. Unfortunately it was not possible in every case to relate estimated velocities to real velocities. From the farmers' willing to categorize measured river velocities a relationship between real and estimated velocity was established as shown in Table 4.5.

Table 4.5 Relationships between estimated and true velocities

Estimated Velocity (EV)	True Velocity Range (TV) ($m\ s^{-1}$)
Slow	0.11 - 0.53
Intermediate	0.32 - 1.81
Fast	1.42 - 4.16

$TV = -.864 + 1.0127\ (EV)$

$S.E._{xy} = 0.57$

$r = .82$

It is apparent that considerable overlap in the categories occurs and that as might be expected the intermediate category covers the largest range. Despite the fact that the independence and applicability arguments have been overcome and that this technique is less crude than others found in the literature, Daugherty (1963), it remains a somewhat subjective and disturbing assessment variable. No other method of measuring velocity seems possible unless very considerable funding is made available.

The field work involved in the collection of these data can be considered as falling into three phases, reconnaissance, measurement and augmentation. The reconnaissance survey was used to locate the flood sites. In dealing with rural flooding it is often difficult to know when and where flooding is taking place. Initial reports usually specify broad geographical regions which have meaning in terms of news value, e.g. the Spey Valley, but which are of little value in locating the exact flood site. In the second phase the field measurement and interviews were carried out and values were assigned to the variables in the manner discussed above. In the final phase the data were checked and augmented where necessary by further information from the farmers. The 137 cases selected for analysis are listed in Table A4.1. This consists of the field data which have been checked, augmented and coded and represents the matrix of data used in all subsequent analysis[1]. It is appropriate to examine the basic data in order to determine the simple survey information it contains and to delineate the areas in which it is applicable.

4.5 The Characteristics of the Collected Data

The mean damage found in the survey was a little under 60 percent. This figure provides confirmation that the doubts expressed previously regarding assumptions of totality are justified. The modal value of 38 observations (27.7% of the total) was of total damage. A full range of damage was found as indicated in the frequency histogram in fig. 4.3. The lowest category is the class of damage in the 50 to 70 percent range but here some 10 percent of the total sample is still represented.

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[1] The computed analysis of these data is lodged with the Department of Forestry and Natural Resources Library.

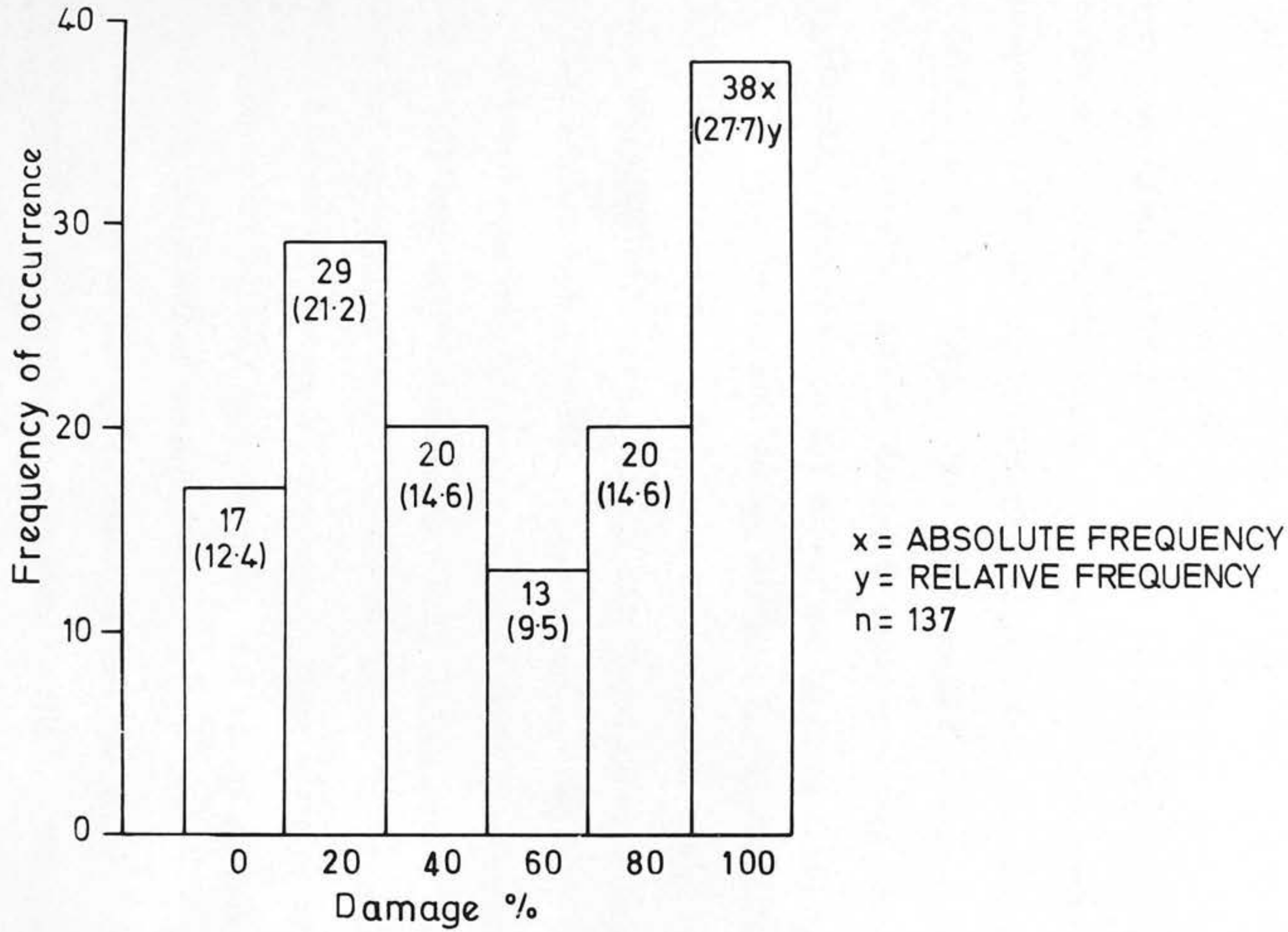


FIGURE 4.3 FREQUENCY HISTOGRAM OF DAMAGE DATA.

The loss data is based upon 60 cases, lower than the representation achieved for any other variable. The range in values for this variable lay between £2.50 and £880.00 per hectare with a mean loss of a little over £100.00 per hectare. This figure is in agreement with the results of a general survey of farm losses in which estimated losses over an area of 500 hectares were £42,500.00 or some £85.00 per hectare. These figures are derived from a general survey of farm losses suffered by the agricultural community in the north-east of Scotland in August 1970. This was a whole farm survey covering 44 farms and in which data on damage to equipment, property and crops were sought. The object of the survey was to throw light upon the variation in areas inundated, losses suffered and types of damage caused. Details of this undeveloped inventory data are not included in this dissertation. It is briefly introduced above to support a loss figure based upon a limited number of cases.

Although some crop types were examined it is clear from Table 4.6 that only four individual crops, wheat, barley, potato and pasture and two combined crops, cereals and roots, yield sufficient numbers of cases for successful analysis. These six crop types do, however, cover the bulk of the main crops that are of spatial importance in the north of Britain.

Full coverage of the age variable was not achieved. No cases of flood damage to pre-emergent crops were examined. The age distribution of the crops in the sample, fig. 4.4a, indicates that the coverage of the remaining age categories is satisfactory although the ripening and mature categories having values of 35.8 and 25.5 percent

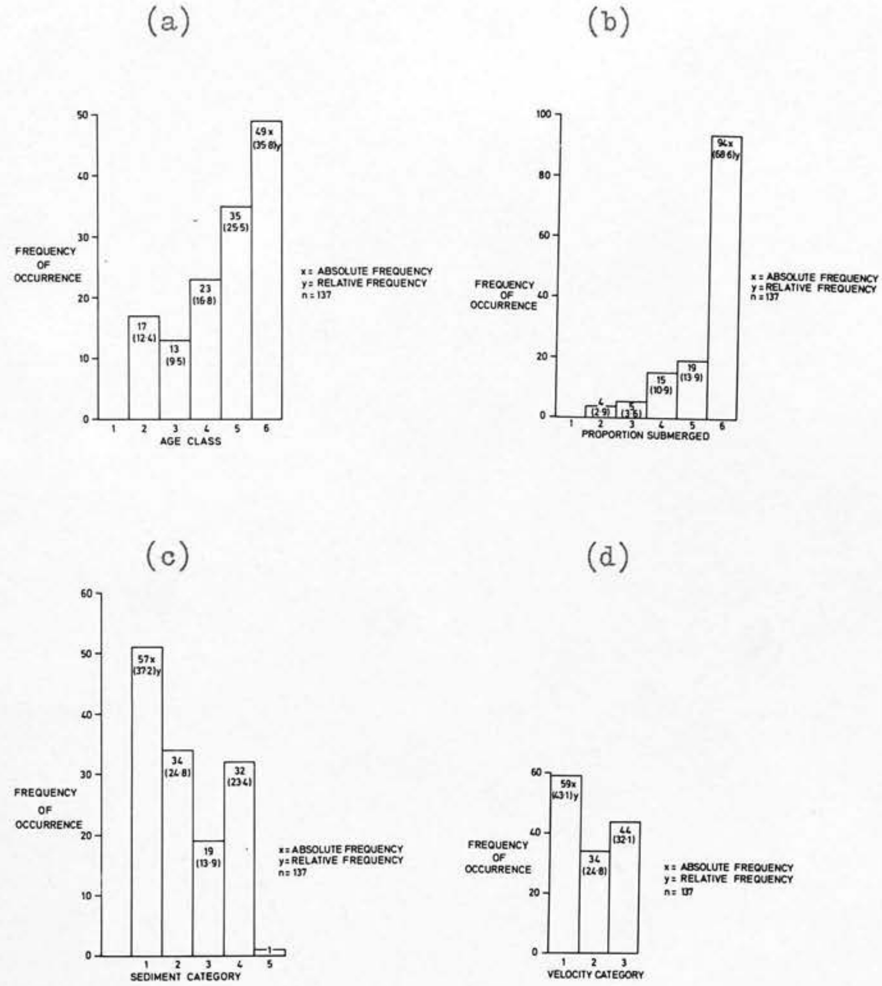


FIGURE 4.4 FREQUENCY OF OCCURRENCE OF THE INDEPENDENT VARIABLES.

Table 4.6 Representation of the crop types in the sample

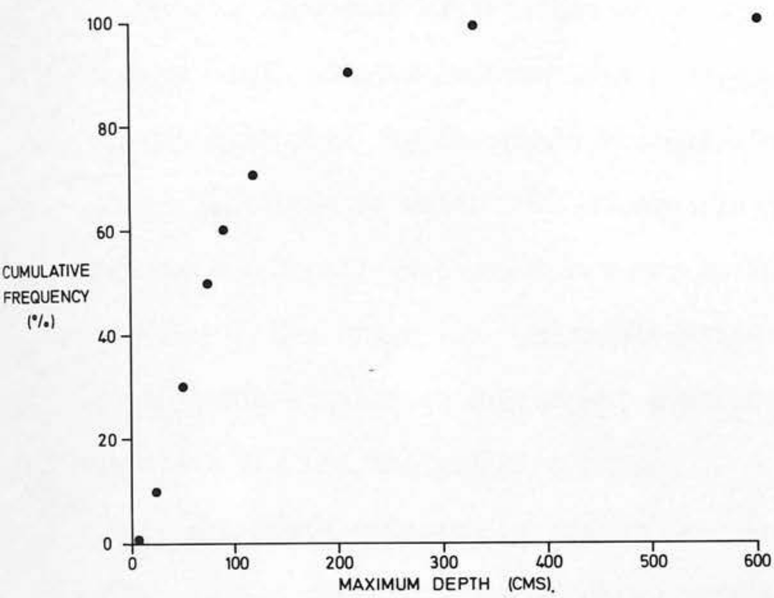
Crop	Absolute number of crops	Proportion of Sample (%)
Wheat	25	18.2
Barley	47	34.3
Oats	8	5.8
Sugarbeet	2	1.5
Turnip	6	4.4
Potato	21	15.3
Cabbage	1	0.7
Rape	2	1.5
Improved meadowland	25	18.2
Cereals	80	58.3
Roots	29	21.2
TOTAL	137	100.0

of the sample respectively may be somewhat over represented. The lowest of the categories represented is seedling with some 10 percent of the total.

Large variations in the depth value, from 8 to 600 cms, were encountered. The mean depth, however, was 120 cms and 75 percent of the sample concerned floods having a maximum depth of less than 180 cms. Fig 4.5a indicates the percentage of the sample having a maximum depth equal to or less than the corresponding depth value. Depth was also related to the height of the crop for theoretical reasons discussed above as the maximum proportion of the crop submerged. The frequency distribution of the proportion submerged data is presented in fig. 4.4b and indicates that over 80 percent of the sample concerns inundations of over 70 percent of the crop height, indeed 68.6 percent of the observations concern total submersion. At low partial submersions the numbers of observations are unsatisfactory. Attention in the future might profitably be given to improving the numbers of observations in these categories. This could be achieved by stratifying the sample so that the conditions at the flood edge, the low flood depth conditions, would be adequately represented.

The mean value for flood duration was 110 hours. The range in values being from 2 to 1,000 hours. However, 96 percent of the observations concern durations below 240 hours. Fig. 4.5b indicates that the bulk of the observations concern flood durations of less than 96 hours. It is likely that the data on short duration floods are more accurate than the long duration data for two reasons.

(a)



(b)

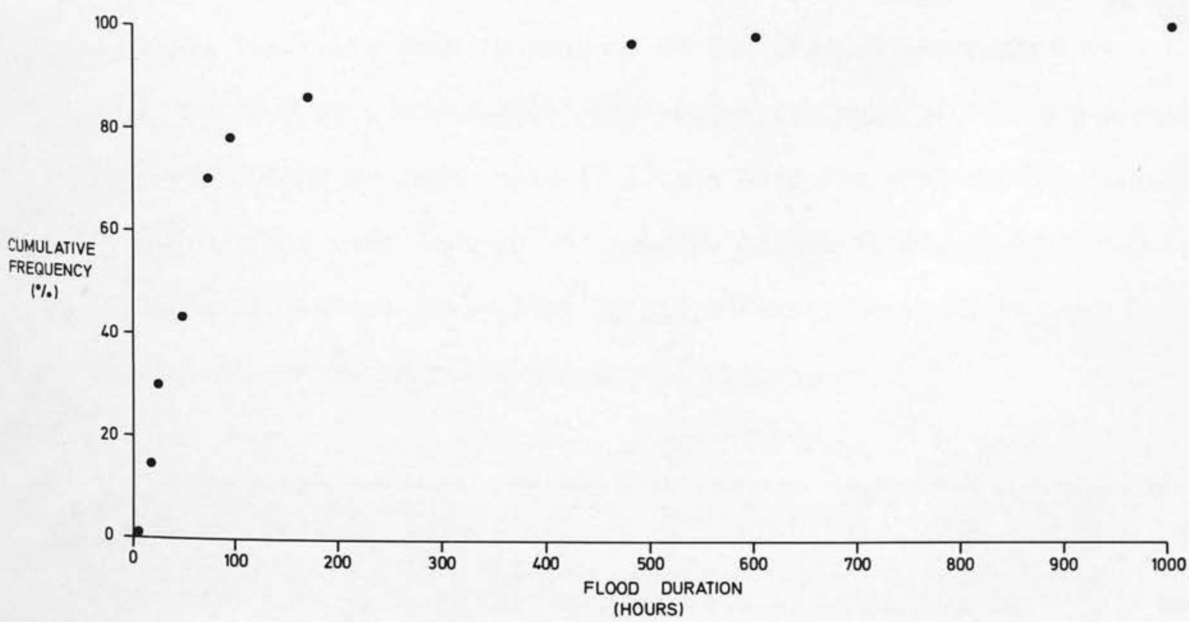


FIGURE 4.5 CUMULATIVE FREQUENCY OF OBSERVATIONS ON (a) DEPTH, AND (b) DURATION.

Firstly, as time passes it becomes less likely that the crop will survive and thus the farmers' interest in gaining access to the area declines. Because of this his knowledge of the time at which the area clears of floodwater becomes less accurate. Secondly, the difficulties of deciding when the flood has receded increase, for unlike the short duration floods in which much of the floodwater recedes following the passage of the floodwater, the water in long duration floods is removed at low rates through infiltration and evaporation. It will be appreciated that this argument applies to the absolute error in the estimate and not the relative error.

The representation of differing classes of sediment deposit is shown in Figure 4.4c. It is clear that all classes are well represented in the sample with the exception of category five. This data deficiency is possibly partly due to the difficulty of dealing with farmers on whose land this form of damage has occurred. It is worthy of note, however, that less than 10 percent of the farmers approached in this study refused to co-operate. The reason for some of the non-co-operation is that in high sediment deposit floods both the crop and the land are destroyed thus some farmers at the time of the flood see little point in flood studies on their land[1]. In general, however, severe deposition covers only limited areas.

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[1] It is the informal policy of DAFS to reclaim such land. However the Department have made no statement of formal policy in this regard and the farmers are often doubtful if the land will be reclaimed.

The final variable studied, velocity, has the frequency distribution shown in fig. 4.4d. It had been anticipated that the intermediate and high categories would be most used by the respondents. The former because of the rather nebulous nature of the term and the latter because the belief of the author was that individual farmers would consider that his flooding was more serious than that of his neighbours and that he would therefore allocate to himself a high category of velocity. The relatively even distribution of the replies over the three categories was satisfactory.

It is necessary to conclude this examination of the basic data by emphasising three points. The first is that the data, while far from perfect, were collected in different circumstances and are perhaps of value in demonstrating that data of this nature can be collected. The second, that the validity of the results is restricted to the range of the data from which the conclusions are drawn. Table 4.7 presents the range of the data in summarised form. The importance of appreciating the range of data is examined in some depth by Draper and Smith (1966). The third that the hypothesis of total damage must be rejected on the basis of this detailed survey of crop damage. In the majority of cases damage is less than total and mean damage lies between 50 and 60 percent of total. This being so it is necessary to continue the examination of the data to throw light on those further problems discussed at the outset of this Chapter.

Table 4.7 Summary of the ranges of the observed data

Variable	Theoretical		Observed		
	Minimum	Maximum	Minimum	Maximum	Mean
Damage	0	100	0	100	55.18
Loss	0	1200	2.47	880	101.3
Crop Type	NA	NA	NA	NA	NA
Crop Age	1	6	2	6	4.7
Absolute Depth	1	NA	8	605	120.4
Proportion Submerged	1	6	2	6	5.42
Duration	1	NA	2	1000	110.5
Sediment Deposit	1	5	1	5	2.255
Velocity	1	3	1	3	1.892

4.6 The Analysis of Single Variable Relationships

It is of little value to proceed directly to the analysis of multiple variable relationships without considering the information that can be derived from the data by simpler forms of analysis. It may be argued that only multivariate analysis may be used in a multivariate situation. However, single variable analysis can achieve some of the objectives of this Chapter and develops an understanding of the nature of the basic relationships from which the interpretation of the results of more complex forms of analysis can proceed. Furthermore the precedent exists through White's (1964) studies in the residential context of examining the relationships that exist between flood damage and individual variables of the flood.

Analysis using simple Chi square techniques was rejected due to the low observational numbers that occurred in some cells thus rendering doubtful the validity of the technique. Instead the damages observed within the various categories of each of the variables examined were determined using a breakdown programme of the Statistical Package for the Social Sciences (SPSS) written by Nie, Bent and Hull (1970). This programme was used for its ability to manipulate large amounts of data in case format. To facilitate the analysis the results of the breakdown programme were fed into a further programme, Outputstats. The output of this programme consists of three parts, (i) a statement of the appropriate statistical technique applied in the programme chosen from the attributes of the population being examined, (ii) the results of the analysis, and, (iii) the significance levels of any differences found in the damages suffered in the two populations.

Table 4.8 attempts to display both the relative damage levels and the significance levels of the differences found in the damages suffered by different crop types. The figures in the cells of the matrix represent the significance levels of the differences between the two crop types indicated by that row and column intersection. The ordering of the crop types in both the row and column headings indicate from left to right and from top to bottom decreasing damage values. The bracketed figure is the mean damage determined for each row and column heading. The 90 percent level is taken as the minimum acceptable probability of significant difference. Table 4.8 indicates that the expected damage to pasture is significantly[1] lower than that of all of the other crops studied. Damage to barley is significantly lower than that to oats and potatoes and is very significantly lower than that to wheat. No differences could be found in the damage suffered by barley and turnip crops and indeed differences between turnip damage and damage inflicted on other crops could be detected only at the 90 percent level in the comparisons with wheat and pasture. Damage sustained by potato and oats was found to be significantly greater than that sustained by barley and very significantly greater than that borne by pasture but no differences could be found in the damages between oats and potato themselves. Wheat damage was very significantly greater than barley and pasture damage whilst no distinctions could be made between the damages

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[1] The term significant difference is used to identify statistical differences at or above the 90 percent level. The term very significant indicates differences at or above the 99 percent level.

sustained by wheat and that inflicted on either oats or potatoes.

Table 4.8 Significance of damage levels suffered by different crops. See text for interpretation.

Increasing flood damage ←

Increasing flood damage ↑	Wheat (77.6)	Oat (77.4)	Potato (71.4)	Turnip (53.4)	Barley (48.6)	Pasture (24.0)
Wheat (77.6)		-	-	90	99	99
Oat (77.4)	-		-		95	99
Potato (71.4)	-	-		-	98	99
Turnip (53.4)	90	-	-		-	90
Barley (53.4)	99	95	98	-		99
Pasture (24.0)	99	99	99	90	99	

It is interesting to note that on the basis of this survey barley is more flood tolerant than other cereals. Table 4.6 indicates that in the survey barley crops were planted in flood prone areas to a greater extent than other cereals. Whether on a national picture barley is planted to a relatively greater extent than other cereals on flood prone areas lies out with the brief of this research. However, in the final chapter this area of research will be considered in relation to other flood research topics that have arisen as a result of this work.

Daugherty (1963) and Sloggett (1970) of the Economic Research Service (E.R.S.) have suggested that differences in the damage proneness of various crops to flooding might be expected. However their results have been derived almost entirely from past records not prepared for this purpose. Up to the present time no single conclusive work exists on this subject but the growing weight of evidence from the analysis of past records by E.R.S., from the results of the field evidence gathered in this study and from the controlled environment physiological work of Greenwood (1967) and Macmanmon and Crawford (1971) indicates that differences in the flood proneness of common agricultural crops do exist. Two separate groups of questions remain to be examined. Firstly, what components of the flood cause damage and to what extent do these components vary from crop to crop? Secondly, to what extent does the farmer perceive both these differences and the components which cause damage? The former question may be partially answered by the results of this survey. The latter question remains to be examined. The results of this survey have shown the crops appear to be differentially effected by flooding and that with the exception of barley the progression of crops from flood prone to flood tolerant hypothesised in Chapter III exists. The tolerance of barley will be discussed at later stages after further evidence has been introduced.

Using the same techniques of breakdown the damage suffered to crops of different physiological age may be examined. Again Outputstats was used to test the significance of differences in the mean. Figure 4.6 is designed on the same basis as Table 4.8 and indicates the significant differences found in the damages sustained by crops of different ages. In addition the inverse relationship between damage and age is displayed in graphical form. Damage suffered by mature crops is very significantly lower than that suffered by all other age classes with the exception of the ripening class where the significance of the difference was much weaker, 90 percent. Similarly but at generally lower levels of significance, 98 and 99 percent, the ripening crops were less damaged than younger crops. No differences were detected in the lower age class crops. An inverse relationship between damage and age is supported by the findings of Mallett and Jasma (1961). These workers dealt only with maize and used monthly damage data. In their study the crop was placed into one of three categories depending on month, namely, preplanting, growing or harvest. They found that damage to harvest crops was about half of that to growing crops. A clear inverse relationship was also found when the data were examined by month. Mallett and Jasma found that the age damage relationship could only be demonstrated at low flood depth.

There is a positive relationship between depth and damage. The correlation coefficient for the 137 pairs of observations is 0.6345 significant at the 99 percent level. However, subdivision of the data by depth and displaying the damage data by its frequency

Increasing flood damage ↑ / Decreasing flood damage →	Emergent (83·6)	Seedling (77·0)	Juvenile (72·2)	Ripening (49·4)	Mature (34·6)
Emergent (83·6)	X	0	0	99	99·9
Seedling (77·0)	0		0	98	99·9
Juvenile (72·2)	0	0		98	99·9
Ripening (49·4)	99	98	98		90
Mature (34·6)	99·9	99·9	99·9	90	X

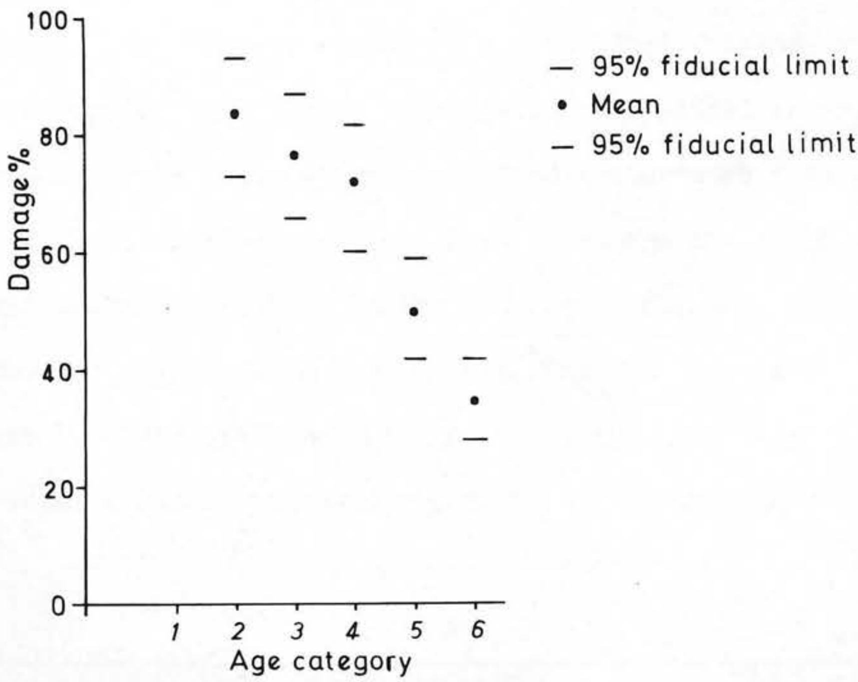

FIGURE 4.6 SIGNIFICANCE OF DIFFERENCES IN DAMAGE SUFFERED BY CROPS OF DIFFERENT AGE CLASSES.

of occurrence (fig. 4.7) indicates that the relationship is a complex one and that damage estimated to be less than 10 percent predominates at low flood depth while at greater depths greater damage predominates. Table 4.9 shows the matrix of significant difference between damage suffered by crops which have been submerged to different extents. It appears that total submersion of the crop leads to significantly greater damage than partial submersion. The extent to which these findings can be explained by the work of Greenwood (1967) is open to doubt. However, it seems that limited oxygen translocation may be one explanation. Greenwood's work on barley has shown that oxygen can enter through the aerial parts of the plant. However, he does point out that under field conditions different results could occur. No other work has been found that relates damage to the proportion of the crop submerged. The establishment of those relationships suggest management adjustments that might be adopted such as earlier planting to increase age and height in areas of marked seasonal flooding in the later crop stages. Similarly the reduction in floodwater depth following the passage of the floodwave by artificial breaching of the levee such that the crop is not totally submerged would appear to be a promising remedial action[1].

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[1]Remedial action of this type was only found in one case in the survey. That case involved a University Experimental Farm.

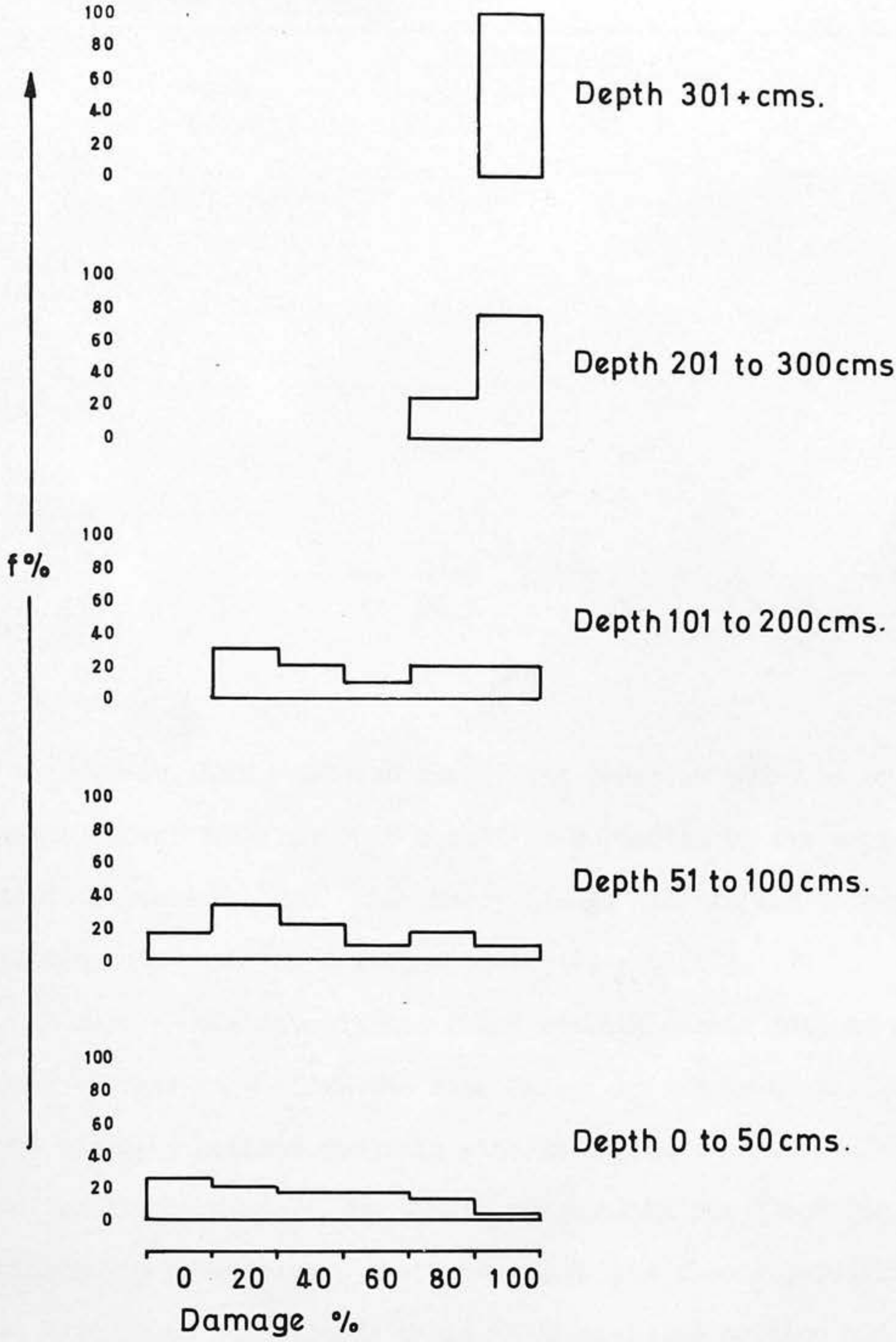

FIGURE 4.7 RELATIONSHIP BETWEEN DEPTH AND VARIATION IN DAMAGE.

Table 4.9 The significance of damage differences by the proportion of the crop submerged

Increasing flood damage →

Increasing flood damage ↓	% Submersion 10-30 (30.0)	30-50 (40.0)	50-70 (40.0)	70-90 (40.0)	90+ (62.6)
10-30 (30.0)		--	--	--	90
30-50 (40.0)	--		--	--	80
50-70 (40.0)	--	--		--	95
70-90 (40.0)	--	--	--		98
90+ (62.6)	90	80	95	98	

No relationship between damage and duration could be established from the survey data and this result is supported by the correlation analysis where r = .199. Daugherty (1963) also failed to establish a relationship with the duration variable, r = .263.

A strong relationship was found between debris deposit and damage. Figure 4.8 shows the mean damage by debris class. Where debris having a maximum particle size in excess of 2 mm had been deposited by floodwaters the damage produced by the flood was significantly greater than that resulting from floods depositing finer materials. In floods where no apparent deposition had taken place damage was significantly lower. It will be remembered however

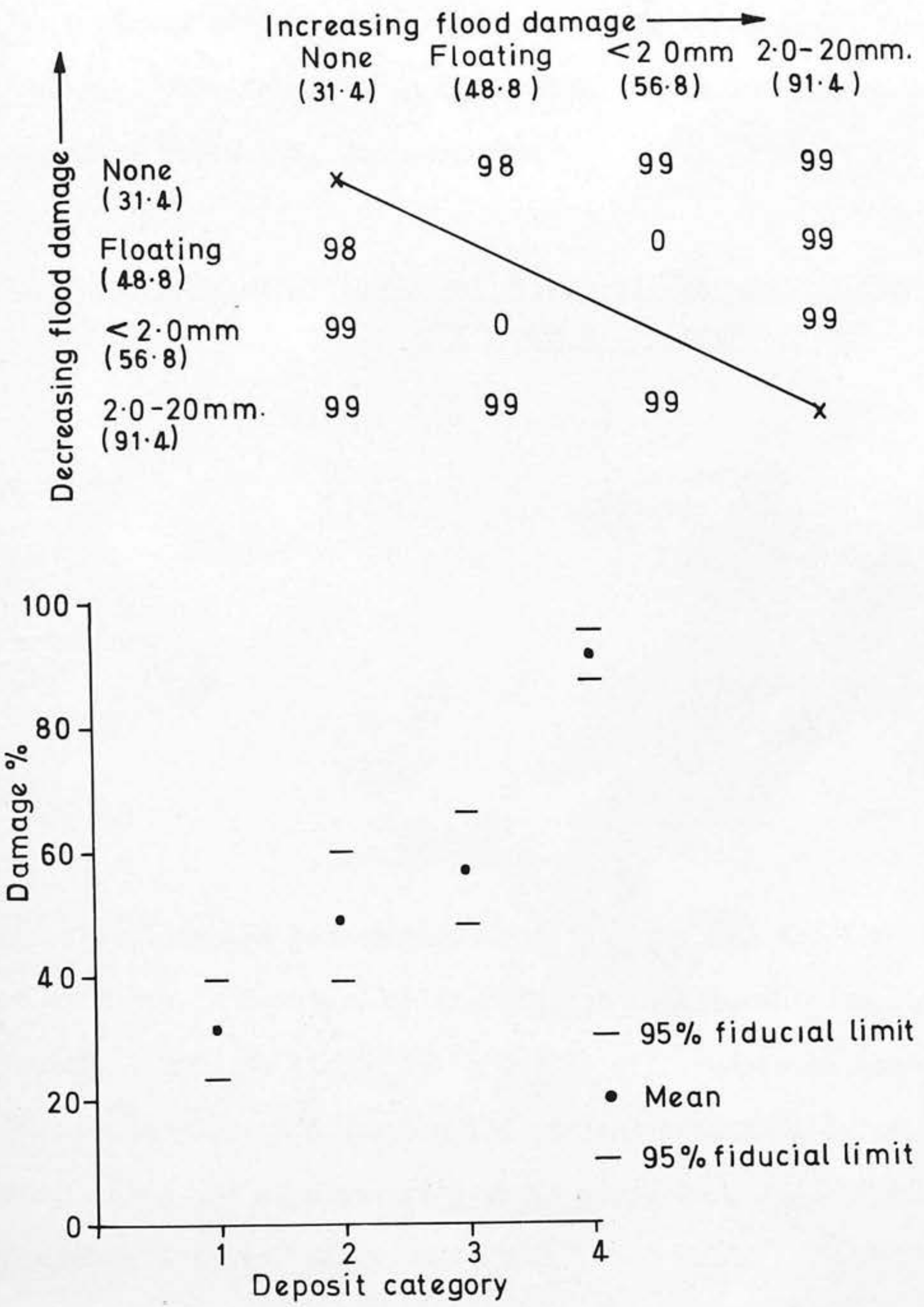

FIGURE 4.8 SIGNIFICANCE OF DIFFERENCES IN DAMAGE SUFFERED FOLLOWING FLOODS OF DIFFERING DEPOSITIONAL CHARACTERISTICS.

that in the Nith floodplain although little debris was reported damage to equipment was considerable due to attempts to harvest crops that had in fact been covered by very fine deposits.

A strong direct relationship is exhibited between damage and velocity. This is shown in Table 4.10 and is in agreement with the work of the E.R.S. quoted above.

Table 4.10 The significance of damage differences in floods of different velocities

	Slow (32.6)	Intermediate (50.6)	Fast (89.0)
Slow (32.6)		99	99.9
Intermediate (50.6)	99		99.9
Fast (89.0)	99.9	99.9	

Relationships between loss and the crop and flood variables were examined. However, no significant relationships could be detected. This is likely to be due to differences in the costs of different crops. For example 100 percent estimated damage to both a turnip crop and a potato crop would yield loss figures that differed by a factor of at least 10.

This analysis of the relationships between damage and aspects of the crop and the flood has been orientated towards clearly illustrating the general nature of the relationships. However the correlation analysis discussed in the next section investigates the specific relationships that exist within crop types between damage and the crop and flood variables. From the results of the survey the following points can be made at this stage. Firstly, total damage cannot be assumed. On the basis of this survey it can be stated that mean flood damage is approximately 55 percent. Secondly, different crops exhibit different amounts of damage. The flood tolerance/proneness of crops approximates that hypothesised in chapter three. Thirdly, in a general sense damage has been related to several specific aspects of the crop and flood.

4.7 Multivariate Analysis

4.7.1 Introduction

In this part of the study the data are examined using correlation analysis, regression analysis and factor analysis. The first form of analysis will be used to determine the strength of the relationship between damage and individual flood variables and to indicate the extent of the intercorrelation of the data. In the second analysis regression is used to identify the relative importance of different flood characteristics in producing damage within crop types. Predictive equations which might be used in the assessment of damage are examined. In the third analysis the data are interpreted to identify the true components of damage. In this manner the regression equations can be logically supported and the intercorrelated nature of the data clarified.

4.7.2 Correlation Analysis

Correlation analysis expresses the relationship between two variables as a single summary statistic, the correlation coefficient. The data are ordinal and in the majority of cases are measured on an interval scale. Rank order correlation coefficients are more appropriate to ordinal scale data whilst Pearson product moment correlation coefficients are more appropriate to interval scales (see Blalock, 1960). While the computational procedures used to calculate these two coefficients differ, they have a common direct relationship to the underlying geometric representation of the relationship and in practice there is no firm agreement among research workers on the selection of coefficient. In the examination of the flood damage data, both Pearson and Kendall coefficients have been used.

Table 4.11 lists Pearson correlation coefficients between damage and the independent variables for the total data and for each crop type. Appendix 4 contains the equivalent correlations using Kendall coefficients, similar tables of loss correlations with the independent variables, and the all data correlation matrix. From these tables the following observations can be made. Firstly, there is a marked intercorrelation between the variables. Secondly, the correlations between damage and the independent variables are much stronger than those between loss and the independent variables. Indeed loss is correlated only with age in the Pearson matrix of all data. Thirdly, the coefficients calculated by rank order correlation and by least square correlation are very similar. This being so the discussion will be limited to the Pearson correlations between damage and independent variables that are included in Table 4.11.

In the all data correlations, the association between damage and sediment deposit is strongest, r = 0.6825. Velocity and depth are similarly strongly correlated with damage whilst age exhibits a strong negative correlation, r = -0.4981. Correlations with proportion submerged and with duration are weaker, duration in fact fails to achieve the levels of significance exhibited in the other correlations. At this stage the interpretation of these figures is that the physical impact of the flood, its "erosive" component, velocity, depth and sediment deposit, cause severe damage and that only when the physical impact of the flood is low can the other variables such as the proportion submerged be seen to relate to damage.

The wheat damage relationships show a lack of correlation in the age, duration and proportion submerged variables. In the case of the proportion submerged this is probably due to the poor spread of the data for that variable. With a better range of data, the results for barley once again show strong correlation with age and proportion submerged. Cereals, the analysis of combined wheat, barley and oats data, gives essentially the same results, strong positive correlations with the "erosive" variables, a negative correlation with age and weaker correlation with other variables, duration being uncorrelated.

A very different pattern emerges from an examination of the damage relationships in potato and root crops. Duration becomes much more strongly correlated with damage, $p = 0.04$, whilst correlations with the remaining variables are generally reduced, particularly in the sediment and velocity variables. Velocity is not significant at 95 percent. A logical interpretation is that at mature crop ages the product is ready for harvest but is protected from the erosive variables by being below ground. Thus duration of the waterlogging becomes an important damage producing variable. Combining data to form the root crop category does not change the interpretation from that for potato.

Damage to improved meadowland pasture correlates highly with duration, sediment deposit and velocity having coefficients of 0.7402, 0.7087 and 0.7169 respectively. Both flood depth variables fail to achieve correlations at even the 90 percent level. Interpretation is more difficult in this case, but it seems likely that prolonged inundation reduces potential grazing time while velocity and sediment deposit are more likely than depth to damage the sward physically.

Because of the intercorrelated nature of the data, an examination of the first to third order partial correlations between damage and the apparently more important simple or zero order correlations was made (see Appendix 4). The use of partial correlations is discussed by Kendall and Stewart (1961) and here it is proposed only to outline briefly the methods used. Partial correlation allows the research worker to control for the effects of other variables. This control is statistical and depends upon assumptions of linearity. The raw data are not selected for constant values of the control variable. The partial correlation between variables i and j controlling for k, $r_{ij.k}$ is derived from the 3 simple correlation coefficients that exist between these variables in the equation:

$$r_{ij.k} = \frac{r_{ij} - (r_{ik})(r_{jk})}{\sqrt{1 - r_{ik}^2 . \; 1 - r_{jk}^2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4.1)$$

In the all data examination, velocity remained a very highly significant damage associated variable, p = 0.001 controlling for depth, duration and sediment deposit, although r dropped to 0.288 controlling for sediment load and velocity. Sediment deposit and depth both remain very significantly associated with damage. In the cereals examination depth is shown to be a possible spurious relationship although this is apparent only at second order partial correlations controlling for velocity and sediment. Velocity and sediment remain significant at p = 0.001 throughout all partials. These results are reflected in examination of the individual cereal crops. A marked reduction in the correlation coefficients between damage and the depth, sediment deposit and velocity variables occurs as control is effected in the root crops. Duration which had been significant in the simple correlations is found to remain significant at third order partials, r = 0.6464, p = 0.02.

Table 4.11 Pearson product moment correlation coefficients between damage and the independent variables for all crop types. Significance levels are bracketed

Variable / Crop	Age	Depth	Part sub	Duration	Sediment	Velocity
All Data	-0.4981 (0.001)	0.6373 (0.001)	0.2717 (0.001)	0.2011 (0.018)	0.6825 (0.001)	0.6598 (0.001)
Wheat	-0.0985 (0.639)	0.7656 (0.001)	0.2979 (0.148)	0.2230 (0.284)	0.7546 (0.001)	0.6376 (0.001)
Barley	-0.5451 (0.001)	0.7646 (0.001)	0.5846 (0.001)	0.0424 (0.777)	0.8691 (0.001)	0.8778 (0.001)
Cereals	-0.4164 (0.001)	0.7010 (0.001)	0.5334 (0.001)	-0.0227 (0.842)	0.7978 (0.001)	0.7752 (0.001)
Potato	-0.4531 (0.039)	0.6504 (0.001)	0.5606 (0.008)	0.4512 (0.040)	0.4994 (0.021)	0.4023 (0.071)
Roots	-0.3955 (0.034)	0.5824 (0.001)	0.3557 (0.058)	0.4833 (0.008)	0.4757 (0.009)	0.4249 (0.022)
Pasture	-0.3819 (0.060)	0.5081 (0.010)	0.2961 (0.151)	0.7402 (0.001)	0.7087 (0.001)	0.7169 (0.001)

Partials of above the third order were not examined. The validity of high order partials has been called into question by a number of workers, for example Davies (1957). This brief examination of partial correlations seems to support the inferences made from simple correlation analysis. In the case of root crops it appears to emphasise the relative importance of the duration variable.

Work by the Economic Research Service of the United States Department of Agriculture, Cotner (1970), over the last ten years has attempted to throw light upon the damage, flood variable relationship. However, only Daugherty (1963, 1966) has examined and published the correlation matrix. The significance levels of the correlations are not included in his results but if no missing values occurred, the degrees of freedom could be as high as 80. If the correlation coefficients are considered on this basis it is found that in tobacco crops velocity is very strongly correlated with damage, $r = 0.6794$, $p = 0.001$, depth is less strong related, $r = 0.3093$ and that duration is the least strongly correlated, $p = 0.002$, of the significant variables. The results for corn which are perhaps more relevant as a comparison indicate that depth, velocity and duration, $r = 0.5179$, $r = 0.3868$ and $r = 0.2631$ respectively are significant damage associated variables whilst age and "average" catchment size are not significantly correlated. It is worthy of note that these American results are not in disagreement with the Scottish Study despite the vastly differing study areas, indicating possibly a generality in these findings. The correlation analyses has served not only to support the findings of the single variable analysis but has indicated that the relative importance of the individual variables in the relationships between damage and flood variables change between different crops.

4.7.3 Multiple Regression Analysis

Situations arise in many field of study in which the value of a variable is determined by the values of one or more other variables. From the correlation analysis and from the analysis of single variable relationships it can be seen that many variables correlate with damage and that therefore the multiple regression model is applicable. A regression equation is a statistical relationship between observed values of two or more variables. The regression model most often quoted is:

$$y = a + b_1x_1 + b_2x_2 + \ldots\ldots + b_nx_n + R \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4.2)$$

Where y is the dependent variable

$x_1 - x_n$ are the independent variables

a = a constant

R = normally distributed residuals

b_{1-n} = unnormalised regression coefficients

This form of the model is used throughout the investigation. Before using the model to analyse the flood damage data it is important to discuss the assumptions, limitations and misconceptions that relate to multiple regression.

Snedecor (1967) points out that a number of terms may be missing from the equations, representing variables which have either not been measured or which may not even be suspected of influencing the dependent variable. In this study, a number of other variables may by hypothesised as influencing flood damage but which at present cannot be successfully measured in the field, e.g. turbulence.

A common misconception in regression is that the independent variables must be independent (uncorrelated) one from the other. The value of the dependent variable depends upon the values of the independent variable. However, the independent variables are independent (causally) of the dependent variable, but not of necessity independent from other independent variables. The problem is clearly one of nomenclature, and in an attempt to solve this problem Kendall and Stewart (1961) suggest the use of dependent variable and regressor variable whilst Draper and Smith (1967) use the terms response and independent variable. King (1969) and Mead (1971) provide lucid comment on the independence problem, noting that the real effect of intercorrelation is to enlarge the standard error.

The assumptions made in the use of multiple regression are discussed at some length by Davies (1957) and Freese (1964). These are:

(i) that there should be constancy of error variance,

(ii) that the deviations of the dependent variable from the regression surface should be independent from one another,

(iii) that the independent variables should not be correlated with the residuals, and,

(iv) that the independent or regressor variables should be measured without appreciable error.

In relation to the last point Davies (1957) believes that in reality the error should be small in relation to the range of the data. From a practical aspect, Malcolm (1970) makes the point that although these assumptions may seldom be satisfied what may be most important is that these assumptions should be appreciated so that the results may be interpreted in relation to the quality of the data.

Kendall (1951) and (1952) has traced briefly the development of multiple regression techniques from Yule and Pearson and both Whitaker and Robinson (1967) and Draper and Smith (1967) provide detailed accounts of the application of the technique. Siegel (1956) discusses the advantages of nonparametric statistics. Regression equations derived from a nonparametric basis have been developed by Mishra (1971). Williams (1972), however, believes that such nonparametric equations have no validity at least as a predictive tool due to the ranking process involved and although equations based on rank correlations were constructed and investigated during this flood study only those based on parametric statistics are used in the following discussion.

Two forms of regression have been used. The first, full regression, in which all of the variables are entered regardless of their contribution to the variance explained or to the significance of the partial. The second, stepwise regression, a powerful variation of the tool which provides a means of choosing from within the independent variables the combination that provides the best prediction with the fewest variables included in the equation. A recursive form of evaluation is used in that the first independent variable included is that which is the best predictor. The second variable chosen is that which in combination with the first provides the best prediction. This process continues until either all the variables are entered, or the maximum number of variables that will be allowed into the equation is reached, or the tolerance level becomes too low to allow further additions. At each step, the optimum variable is chosen, given the variables already entered in the equation.

It is convenient and informative to examine the results of the all crop regression analysis as a preliminary to the examination of the results from the individual crops. In this first examination the meaning and interpretation of the statistics presented in the text and in Appendix 4 will be discussed so that repetition will be avoided in the examination of the results of later analyses.

Table 4.12 gives the results of the regression analysis of the all crop data. Interest should initially focus on the three statistics that define the overall performance of the regression equation:

(i) the multiple correlation coefficient r,

(ii) the square of r,

Table 4.12 Full Regression Analysis for the all crop data

Multiple r	0.81807	Analysis of Variance	d.f.	F
r square	0.66924	Regression	6	43.8396
Standard Error	21.4726	Residual	130	

Variable	B	Beta	Std.Error B	F
Velocity	12.3928	0.29311	3.1968	15.031
Age	-9.0636	-0.34200	1.5362	34.811
Depth	0.0786	0.23244	0.0244	10.325
Partsub	-2.3592	-0.06587	1.9924	1.402
Duration	0.0548	0.23496	0.0126	18.821
Sedload	5.6750	0.18761	2.6312	4.652
Constant	58.1472			

Variable	Multiple r	r square	r square change
Velocity	0.65979	0.43533	0.43533
Age	0.71880	0.51688	0.08135
Depth	0.77757	0.60462	0.08794
Partsub	0.77900	0.60684	0.00222
Duration	0.81081	0.65741	0.05057
Sedload	0.81807	0.66924	0.01184

(iii) the stand error of the estimate, and,

(iv) the results of the analysis of variance which indicates the possibility of the result being simply due to chance.

The multiple correlation coefficient is important because the square of this value, r square, may be interpreted as the proportion of the total variance of the dependent variable that has been explained by the equation. In this case r squared indicates that the equation explains 67 percent of the variance in damage. This is a surprisingly high figure when one considers the variability that must be introduced by examining a range of crops. Such a figure suggests that the impact of crop type may not be quite as important as might have been expected. The standard error represents the typical error in the prediction. The standard error is the standard deviation of the residual and since the residual has a mean of zero, the standard error indicates the size of the residual. Since the residual is merely the difference between the observed and predicted values the standard deviation of the residual is equal to the standard error of the prediction. In this case it should be noted that the standard error is a little over 20 percent an improvement over the difference between assumptions of totality and the real mean damage, 50 to 60 percent. The well known 'F' statistic, the ratio between the mean squares of the regression and the residual is examined by reference to a table showing the probability of gaining that 'F' value by chance. In this case F = 43.84 with 6 and 130 degrees of freedom, indicating that the equation as a whole is highly significant.

Attention should now be given to the statistics that relate directly to the variables in the equations. These are:

(i) B, the slope of the regression line,

(ii) the standard error of B,

(iii) Beta, the slope of the regression line for a normalised equation containing standard units, and,

(iv) the F statistic which relates to each variable in the equation.

Of immediate interest is the sign of the regression slope. In this case it is noted that age and partsub both have negative values indicating an inverse relationship between damage and these variables. The reliability of the sign can now be examined. If B is large in relation to its standard error then it is likely that the sign attributed to B is correct. This can be tested for in the F statistic which relates B to its standard error. F is calculated as (B/Standard error)^2. If in this case the F statistic that refers to the age and partsub variables is examined, partsub is found to be barely significant but age is seen to maintain strong inverse relationships with damage, a result that has persisted from the single variable and correlation analysis.

From the F statistic it is noted that velocity, sediment deposit, duration and depth are significant. Having examined the sign of the regression line and the reliability of the sign through the standard error and F statistics, attention now rests on the magnitude of the slope of the regression line. However, since scales of different ranges are used it is necessary to express the B in standard units. The standardised B, Beta, for any variable i is derived from the equation:

$$Beta_i = B_i \; S_i/S_o \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4.3)$$

where S_i is the standard deviation of the i th variable and where S_o is the standard deviation of the dependent variable.

In the all crop data it is clear that age and velocity are the most important variables, depth, duration and sediment deposit are less important and that proportion submerged is least important.

The last items of information that are contained in Table 4.12 are in the summary table showing the increase in the multiple correlation coefficient and in the square of that coefficient with the addition of each variable to the equation. The real increase in explained variance with each addition is shown in the RSQ change column.

In addition to these statistics, the stepwise regression provides four further items of information relating to the variables that are not yet entered into the equation:

(i) the beta value that variable would have if entered at the next step in the regression,

(ii) the partial correlation between that variable and the dependent variable controlling for the independent variables already entered in the equation,

(iii) the tolerance value ranging from zero to one which, if it has a low value, indicates that the variable is merely a linear combination of variables already in the equation. If tolerance has a high value it indicates that a new dimension is being added to the equation. Tolerance is related to beta and to explained variance, $r^2 = \text{beta}^2 \times$ tolerance, thus large beta's which add little to the explained variance have low tolerances, and,

(iv) the F statistic.

If the stepwise regression for the all crop data, Appendix 4, is examined, it is found that sediment deposit is the variable that explains the greatest variance, 46.6 percent, and that age explains a further 7 percent. With the addition of duration and velocity, explaining almost 6 and 5 percent respectively the total explained variance reaches 64 percent. The addition of the remaining variables raises this value by less than 3 percent. The combination of the data for the various crop types has the effect of allowing all the variables to appear more or less significant.

The analysis of the major cereal crops wheat and barley, together with the cereals analysis, of the combined wheat, barley and oats data also produces interesting results. In the wheat damage regression, Appendix 4, the significant equation, F = 9.16, explains over 75 percent of the variance and has a standard error of 15 percent. In the partials age has a positive and depth a negative beta coefficient but the F tests on both of these variables are not significant.

The F tests on velocity, proportion submerged, and duration are, on the other hand, all significant. The stepwise regression reveals that depth is the variable that explains the greatest amount, 58 percent, of variance and that sediment deposit, velocity and age may be added to the regression without severely affecting the F value significance. At this stage the age slope coefficient is negative. The addition of proportion submerged and particularly duration causes other variables to assume insignificant partials and effects the rational of the equation. In effect a better prediction is achieved by reducing the meaning of the equation. With only four variables in the equation, depth, sediment deposit, velocity and age, nearly 70 percent of the variance is explained, the standard error being 17 percent.

Turning to the analysis of barley, Appendix 4, where some 47 cases were examined, it is found that the explained variance is over 90 percent and the standard error of the estimate is a little over 10 percent. The F value for the equation as a whole is very highly significant. The beta values indicate that sediment deposit and velocity are the most important variables. As in the case of wheat, age has a positive but not significant slope whilst duration has a negative slope.

In the stepwise regressions, velocity, sediment deposit and duration are entered and explain 91.5 percent of the variance, the addition of the remaining variables explains less than a further 1 percent variance.

As may be expected, the cereals results represent an amalgam of those of wheat and barley influenced by the addition of the results for oats. The results in Appendix 4 indicate that 77 percent of the variance is explained. The standard error is 17 percent and the equation as a whole is significant at $p = 0.01$. Sediment deposit and velocity have high beta values. Duration has the lowest beta value, has a negative slope and is non significant in the F test. Age also has a negative slope but, in contrast to duration, is highly significant. From the stepwise regressions it is noted that sediment deposit, velocity, age and depth are all significant variables which together explain 77 percent of the variance.

An examination of the regression analysis for potato crop data indicates that the results are significant at the $p = 0.01$ level, $F = 5.92$, and that 72 percent of the variance is explained, the standard error of the estimate being 20 percent. In the partials only duration is highly significant. Depth and age also have high F values but depth is the only other variable that is significant, and that in the 90 percent range. In the stepwise regression, however, depth, duration and age all prove significant. Depth is entered first explaining 42 percent of the variance. In total these three variables explain 71.3 percent variance.

The analysis of the data for all roots crops, Appendix 4, yields an equation significant at $p = 0.01$, explaining 68 percent of the variance and having a standard error of estimate of 21 percent. Again the key variables appear to be non "erosive" elements of depth, duration and age. Depth is the first variable to be entered into the stepwise regression explaining 34 percent of the variance, which together with duration raises explained variance to 42 percent. The addition of the variable sediment deposit causes depth to become insignificant. The addition of age does not effect the significance of any of the variables already in the equation. Sediment deposit becomes insignificant upon the addition of proportion submerged and velocity and the equation now takes the form of that which appeared in the full regression.

Consider now the data from the cases of flooding to improved meadowland pasture, Appendix 4. Here an equation has been developed that is significant at $p = 0.001$ and which explains over 87 percent of the variance, the standard error being 12 percent. Duration, age and depth are the variables that are significant in the full regression. Of these, age has a negative slope. The stepwise regression yields little further information, duration alone explains 55 percent of the variance and with age explains almost 80 percent variance. Duration, age and depth together explain 86 percent of the variance. The high negative beta coefficient of the age variable supports the view that damage to pasture is much greater at younger age classes, probably particularly so before crop closure. This view stems from logical deduction, discussion with farmers and from personal observation.

It is useful at this point to compare these results with those obtained by American workers in the same field[1]. The Scottish study

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[1]Work by Daugherty (1963 and 1966) and by Sloggett (1970) resulted in reports for administrative use only. The author is grateful to Mel Cotner for the release of these reports. The final result of Sloggett's work is not yet available.

appears to have made improvements in explained variance and in standard error. At best Daugherty gained 55 percent explained variance and at worst 4 percent. Equivalent figures from the Scottish data are 91 percent and 68 percent. It is important to consider why such an improvement might occur. It is likely that Daugherty himself has perceived the essential explanation when he states:

> "additional observations of damage do not seem to improve the reliability of damage estimates .... the alternative seems to be to obtain more precise information."

Daugherty's evaluation, which the author agrees with, is that more or different variables need to be examined with more care. Consider, for example, the age variable. In the ERS study this was measured as the number of days since planting, but in the United Kingdom at least such a classification would result in crops of the same developmental stage having very different "ages". The use of the drainage area variable in the ERS studies can be questioned both on its method of calculation and on the rational of including such a variable in the first place. All of the other variables relate to aspects of the floodwaters or the crops themselves. The drainage area seems to be a variable more likely to relate to the cause of the flood. Why should it be chosen in preference to say river slope or discharge? Furthermore, the method used for calculating the drainage area variable leaves much to be desired. An "average" drainage area is calculated for the whole of a catchment and this figure divided by two and rounded to a whole number is used as the drainage area value for all cases studied in that catchment. This form of estimate seems unnecessarily complex and its use seems surprising when more accurate estimates could have been made.

It will be recalled that, in the ERS study, the method of calculating the velocity variable makes the velocity estimate dependent to a considerable extent upon the damage estimate and thus to some extent invalidates the use of that variable in the analysis. The use of such "linked" estimates has been commented upon previously and the author does not propose to reiterate these comments but would wish to note that the measure of damage used in pasture crops - the ratio of the number of days grazing lost during the flood to a number of days grazing normally available in a season - may be questioned on the same basis.

The essential differences in the studies that might explain the apparently improved results are, therefore:

(i) the avoidance of "linked" variables,

(ii) the use of a developmental age variable,

(iii) the rejection of a catchment area variable and similar variables, and,

(iv) the use of a sediment deposit variable.

There are, however, important similarities between the Scottish and the ERS studies in that all common variables operate in the same manner.

The results of the regression analysis reflect the conclusions drawn from the correlation analysis, as one might expect as they derive from the same source, the covariance matrix. The equations are all significant at high levels, $p = 0.01$. The explained variance on average is above 70 percent. The intercorrelation of the independent variables, though it means increased standard errors of the estimate, does allow satisfactory equations to be drawn from varieties of variables thus allowing flexibility in the variables measured in any attempt to utilise the predictive abilities of these equations.

Draper and Smith (1966) use three further tests of the regression equations, tests which are not heavily reliant upon the assumptions made to justify the validity of the statistical significance tests. These are: Are the coefficients reasonable? Is the equation plausible? and, is the equation usable? The equations appear to satisfy these criteria. The coefficients seem reasonable. Their value in relation to their range, the beta coefficient, indicates that all of the variables contribute significantly to damage. That the equation is plausible is to some extent determined by the choice of the variables that were to be examined in the first instance. Each variable was chosen because it could rationally be expected to contribute towards damage. In considering plausibility one could question the remaining factors that might influence damage for the list of variables included in the examination was not exhaustive. However, it will be recalled that the high explained variances indicate that a number of the important variables have been examined. The use of the equations will be examined in the next chapter.

4.7.4 Factor Analysis

The use of multiple regression is limited to the estimation of the value of a dependent variable from the values of a number of independent variables. It is not a tool that is suitable for the investigation of the relationships between variables. At best it may be used to identify the relative importance of the major independent variables. As the data become more intercorrelated and complex, (as has been shown to be the case in flood damage relationships), the information value of regression declines. The logical selection of dependent variables in the formulation of the research problems and the analysis of single variable relationships do not attempt to find any underlying pattern in the data, a pattern which in this intercorrelated data seems likely to exist. To attempt to identify this pattern, factor analysis was applied.

Factor analysis must be considered one of the most flexible analytic tools available. In what must be the major reference text to applied aspects of factor analysis, Rummel (1970), notes ten uses of factor analysis. However, in the flood study factor analysis is used only to test the hypothesis that a simpler pattern of interrelationships exists that is subject to logical interpretation in terms of flood damage production. Tukey (1951) uses the simple expression "to boil down" data[1] and indeed this is one of the major uses of factor analysis.

[1]Thurstone (1947) is more elegant in relation to his views on factor analysis: "it is the faith of all science that an unlimited number of phenomena may be comprehended in terms of a limited number of concepts..."

To achieve this data reduction factor analysis replaces the variables by transformed variables (dimensions). The concept being that the fundamental variables may not be directly measurable and that the natural variables, for instance, depth and duration, are used solely because they are measurable separately and conveniently. The terms "natural" and "fundamental" were first coined by Box (1954). In the analysis the data are examined to determine whether or not underlying fundamental components can be determined. In the words of Rummel (1970):

> "factor analysis uncovers the independent "sources" of data variation. Because interdependencies may exist between the data, factor analysts are asking whether the same amount of variation in the data can be represented equally well by dimensions smaller in number than the columns necessary to represent the data."

The two major forms of analysis used in this study, principal components analysis and common or factor analysis, have been discussed by Rao (1955). The theory and method used in component and factor analysis have been described by a number of authors. Adcock (1954) provides a non mathematical treatise of the subject and Rozeboom (1966) although giving a more mathematical orientation than Adcock does give a lucid account of factor analysis (and multiple regression).

The application of factor analysis is covered, however, <u>par excellence</u>, by Rummel (1970). Factor analysis has been greatly neglected in the natural sciences and indeed it is only recently that the technique has gained favour in the wider social sciences. In the United Kingdom Jeffers (1966 and 1967) has attempted to illustrate the flexibility of this type of analysis by applying it to both <u>Adelges</u> specification and the determinants of pit prop strength. In flood studies Roder <u>et al</u> (1961) used components analysis but give so few details of the model and data that the reader is unlikely to gain benefit from the paper. The author is unaware of flood studies in the United Kingdom in which factor analysis has been applied.

Factor analysis like most techniques has been criticised on a number of grounds. Firstly, in relation to scales: Lawley and Maxwell (1963) suggest that the analysis is suspect under non interval scales and that the underlying data must have a multi normal frequency distribution. Corrlett (1963) feels that the interpretation will be valid if the researcher bears in mind the original nature of the data. Rummell (1970) believes that the problems stem from misconceptions and that the near multi normal distribution refers only to statistical significance tests and that the data can be meaningfully applied even to nominally scaled presence or absence data.

A second criticism of factor analysis has been that it assumes additivity and linearity in the data. It does not, in effect; it means that the relationships between functions are analysed in terms of linear vector fields (see for instance Ahmavarra and Markkanen (1958) or McDonald (1967)). A third criticism is that the technique is arbitrary and that different investigators will arrive at differing conclusions from the same data base. There is some validity in this criticism and so in this study various factoring and rotation methods are used in order to test if widely differing conclusions would result.

The remainder of this discussion follows closely the research report section, 23.2, of Rummel (1970) although details of the research question, and the selection, measurement, collection and characteristics of the data have already been covered. In this study the analysis is based upon the correlation between variables (R type factor analysis) from which initial factors are extracted either as defined factors, the principal components solution, or as inferred factors, the classical or common factor solution. Essentially the difference lies in the inclusion in the main diagonal of the matrix of unities in the components solution and of some estimate of communality in the factor solution. In this case the estimate of communality that was used was the squared multiple correlation between a given variable and the rest of the variables in the analysis.

Rotation to a final solution was carried out using orthogonal rotation techniques. The use of oblique rotation procedures was not attempted:

(i) because of the satisfactory results gained from the orthogonal rotation, and,

(ii) due to the difficulties involved in interpreting the results of oblique rotation.

Two types of orthogonal rotation were used. The first, quartimax, attempts to reduce the complexity of a variable by loading a variable high on one factor and low on the remaining factors. Quartimax, then, attempts to simplify the rows of the factor matrix. The second method, varimax, attempts to simplify the columns of the matrix by maximizing the variance of the squared loadings. Essentially one is seeking only high and low loadings on the factors for the square on unity and zero loadings will be greater than the square on a similar number of "mean" loadings. Gutman (1954) has indicated the dangers inherent in presetting the numbers of components to be extracted. Gutman prefers that limitations on eigen value should be the control on numbers of extracted components and in this study only those components having an eigen value greater than 1.0 are selected. This value was also adopted by Jeffers (1967).

The results of both the principal and factor analysis for the total data and for the six major crop types studied are given in Appendix 4. One table of results comprising the initial factor matrix, associated eigen values and the rotated factor matrix is included for each form of factoring and each type of rotation.

In the all data component analysis 75.3 percent of the variation is explained in three components. The first component loads heavily upon depth, sediment and velocity, factor loadings all exceed 0.8. This is interpreted as the factor which represents the erosive force of the flood. It is a measure of the immediate physical damage suffered by the crops. The second factor loads highly upon duration and moderately upon age. The factor loadings of the physical variables is very low. This may be interpreted as the factor of the flood which causes damage from a biological basis. It seems likely that the longer the duration of the flood, the greater will be the build-up of toxic products of anaerobic respiration, for example, ethanol. The third factor loads highly on proportion submerged. It is a measure of the importance of over crop flooding seen in the single variable relationships and may reflect the possibility of translocating oxygen from the aerial parts during times when the roots are in an anaerobic environment.

In the cereals analysis two factors explain almost 70 percent of the variation whilst a further factor having an eigen value of slightly below 1 (.922) explains a further 11.5 percent variance. Again the first factor appears to be a measure of the physical impact of the flood scoring very highly on depth, sediment and velocity and moderately on proportion submerged. The second factor loads heavily upon age and moderately on duration. Again this grouping of variables can be interpreted as the biological component. The same pattern appears in the factor analysis, differing only in the low duration loading in the second factor.

Barley follows much the same pattern as the cereals analysis. Two factors explain 91 percent of the variation in the varimax rotated component solution. In the factor and components analysis using both forms of rotation to a terminal solution groupings of physical damage variables and "biological" damage variables are identified. Sediment deposit and velocity score highly in all analyses with depth and proportion submerged also scoring in the components analysis. Age and duration score highly in the second factor although duration has a low score in the quartimax components solution. In the factor analysis the first factor extracted is the "biological" group whilst this order is reversed in the components analysis.

A third factor is extracted in the wheat analysis. Again the physical component is easily identified but the "biological" factor, breaks down into two factors. The first which loads heavily on age and, in the principal components analysis, moderately on duration and the second which scores heavily on proportion submerged and duration. This third factor appears in all wheat analyses. As in the barley analysis the physical factor is extracted first in the components analysis and last in the factor analysis <u>but in all cases these same factor groupings are extracted</u>.

Much the same picture emerges in the analysis of flood damage to potato although in this case duration loads heavily on both the second and third factors perhaps reflecting the apparent importance of duration in the potato regressions and correlations. In the analysis of pasture damage two factors are extracted, the first loading on depth, sediment and duration and the second on sediment and velocity, (in the varimax components solution age also scores on both factors). Interpretation in the case has to be very tentative. It seems possible that the second factor is the physical damage factor.

The results of most of the analyses are logically interpretable. There is substantive agreement between the components and the more realistic factor results. In all of the crops studied two to three factors explain 70 to 90 percent of the variance. In general a physical component is identified which will cause immediate damage. For example, the breaking of stems in cereal crops, the undercutting of turf in pasture crops or the destruction of almost any crop by severe debris deposits. In addition, a factor which has been termed the "biological" factor has been identified. Here the damage results from biological processes in which time is important. Finally, a third component is found which scores heavily on age only. It seems then as if the damage situation is essentially simple and that few underlying dimensions are represented.

4.8 Conclusion

The work reported in this Chapter has indicated that totality is not a justifiable assumption. Estimates of flood loss based on such assumptions might easily have to be reduced by a factor of about 0.5. It would appear that crops are differentially damaged by floodwater and that the hypothesised progression of flood proneness suggested in Chapter 3 is essentially correct. Barley, however, seems to be more flood tolerant than might be expected. The correlation analysis indicates that there is a particularly strong relationship between damage and the proportion of the crop submerged in the case of barley and the literature suggests that barley is a plant that might be able to take advantage of aerobic conditions in the aerial parts during times of waterlogging of the root system. This then is the first field evidence that has been found to support laboratory studies of flood tolerance through oxygen translocation.

It has been possible to establish that damage can be related to a number of characteristics of the flood and the relative importance of these characteristics appears to vary between crops. Duration of flooding appears to be much more important in root crops and pasture than in other crops. Depth, sediment deposit and velocity appear to be particularly important in the production of flood damage in cereals. The data have been shown to be particularly intercorrelated but when examined using factor analytic techniques it was found that the damage process could be subjected to logical interpretation on the basis of two to three underlying dimensions.

The major problems associated with the variables themselves are that some of them cannot be collected on a truly interval scale and that the distributions of the variables are complex. It is shown by data subdivision and comparison that for some crops these variables are very strongly related to damage and this indicates that for predictive use research is needed into methods of determining these variables on an interval scale. Daugherty (1963) believes that:

> "the regression equations surely will estimate damage with at least the level of confidence of the present procedures used in estimating damage factors in watershed planning."

This may be true but not due to the quality of the equations but because of the major problems that beset agricultural flood loss assessment at present. The continuation of the USDA work on this subject (as yet without conclusion) suggests that the USDA does not consider the equations to be adequate.

CHAPTER V

Flood Loss and Flood Loss Reduction in the Study Area

5.1 Introduction

In previous Chapters of this thesis the effects of the structural protection of an agricultural area against flooding have been examined both in terms of changes in the frequency and extent of flooding, and in terms of the induced changes in land use and land tenure which appear to have taken place. This Chapter seeks to throw light upon a third major effect of flooding and flood protection, the financial effect. Initially the Chapter concentrates on assessing the flood loss in the Nith floodplain and on demonstrating the effects of applying the assumptions examined in the last Chapter. Thereafter the Chapter examines estimates of flood loss reduction in relation to the expenditure made on protection. Comment is made:

(i) on the stringency of economic tests made prior to the decision to approve the erection of protection works,

(ii) on the insurance premium calculated to be necessary to protect the farmer against residual hazard and against the full flood hazard, and the availability of flood loss insurance in an agricultural area such as the Nith, and,

(iii) on the rationality of the induced changes in land use.

Four broad strategies are examined in the assessment of flood loss. In the first strategy the flood losses are calculated from flood loss estimates made in other Scottish floods. In essence this is the method that underpins present potential flood loss assessment. In the second strategy the arguments put forth in the introduction to the previous Chapter are accepted and therefore loss and damage are differentiated. Estimates of the capital at risk for each crop of importance in the Nith floodplain are made and a weighted capital at risk measure is determined. Estimates of loss are prepared on the following bases:

(a) under assumptions of totality,

(b) using general damage factors determined from the study of flood damages in the North East of Scotland, and,

(c) using a weighted damage factor.

In the third strategy it is recognised that information is lost by assuming a mean capital at risk in a year. Since the months when floods have occurred are known the monthly capital at risk can be used to calculate the flood loss for each flood. These values can then be cumulated to provide a total flood loss figure. Once again this method is applied using totality, damage factor and weighted damage factors.

Finally the fourth strategy investigates the technical feasibility of using regression equations to determine damage factors for specific fields during specific floods and thereafter relating the damage factor to the capital at risk in that field in that month. Loss in this case will be cumulated first by field and then by flood to determine a total value for flood loss.

5.2 Strategy I

In Strategy I the flood losses are determined from knowledge of the total areas flooded with and without protection and from an estimate of the loss per unit area. In the Nith area no comprehensive estimates of flood losses have been made, despite the presence of protection works which have been, at least partially, publicly funded and despite the three floods that have occurred in the last decade. For this reason the flood loss estimates made during the North East of Scotland floods have been used in this part of the study. It will be useful to the reader if the methods employed are stated formally. The total flood loss, FL, is determined from the sum of the areas, A, inundated in each flood, i, multiplied by the unit loss estimate, UL, thus:

$$FL = \sum_{i}^{1} A_i \, UL \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5.1)$$

The numbers and extent of floods under protected and unprotected situations have been determined in Chapter II for both the period of protection and for the 1960-70 decade. These are shown in Table 5.1. This decade is of interest because of Harding's (1972) statement of the increased flood severity in this period and because the Nith inhabitants have also voiced this opinion. It will be recalled that losses per hectare in 1970 were estimated on the basis of field survey to have been approximately £100 and on the basis

Table 5.1 Flood loss estimates (£) determined through Strategy I

	Protection Period	1960-1969 Decade
Unprotected total flood area (hectares)	3,369	1,959
Protected total flood area (hectares)	1,038	884
Reduction in inundated area (hectares)	2,331	1,075
Unprotected flood loss (UL = £100)	336,900	195,900
Protected flood loss (UL = £100)	103,800	88,400
Flood loss reduction (UL = £100)	233,100	107,500
Annual flood loss reduction (UL = £100)	10,134	10,750
Unprotected flood loss (UL = £85)	286,365	166,515
Protected flood loss (UL = £85)	88,230	75,140
Flood loss reduction (UL = £85)	198,135	91,375
Annual flood loss reduction (UL = £85)	8,615	9,138

of a whole farm survey to have been £85. These figures are used as the unit loss estimates and are presented in Table 5.1 below. The use of both loss estimates in Strategy I gives an estimated annual flood loss reduction of between £8,600 and £10,700.

Recourse to this method involves making the assumption that the proportions of different crops are similar in the area from which the loss estimate is taken and in the area to which the estimate is applied. Although both the estimate and application areas are in the lower valley floodplains of major rivers, comparison of the data contained in Table 4.6 and Figure 3.3b indicates that the distribution of crops is not similar. In the Nith area there is more pasture, a low cost low damage crop, and a smaller area of root crops, a high cost, high damage crop. In addition, in the agricultural context the time at which the estimate is made can affect the accuracy of loss determination made for floods which occur at other times. In the Nith study this is likely to mean that loss without protection will be overestimated relative to loss with protection.

5.3 Strategy II

In Strategy II it is recognised that there are practical drawbacks to the use of estimates based on loss, and fundamental problems associated with communality which may affect the accuracy of the initial estimates. Because of this the second Strategy works from the basis of damage and determines loss from costing figures prepared for crops in South West Scotland. A weighted mean capital at risk (WMCAR) is calculated from the weighted capital at risk (WCAR) for each month, m, from the equation:

$$\text{WMCAR} = \left(\sum_{m}^{1} \text{WCAR}_m\right)/m \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5.2)$$

The weighted capital at risk for each month is determined from the capital at risk for a crop, j, in month, m, CAR_{jm}, weighted by the proportion of the floodplain area covered by crop, j, pj, from the equation:

$$\text{WCAR}_m = \sum_{j}^{1} \left(\text{CAR}_{jm}\, p_j\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5.3)$$

Since the proportions of the floodplain under different crops have been determined by survey and the results reported in Chapter III the pj's are known. Consider now the costing data.

5.3.2 Costing Data

A number of stages in the cropping cycle can be identified at which significant changes in the cost structure are encountered - changes which will be associated with flood losses. These are:

(i) while the damaged crop is immature and replanting is still feasible,

(ii) while the damaged crop is immature or mature and replanting is not feasible, and,

(iii) when the crop is mature, harvested and damaged in storage.

The last case is not considered in this analysis because the farm buildings in the Nith floodplain are generally situated on small raised knolls affording considerable flood protection and therefore no examination of damage factors to stored crops was undertaken.

When a mature or immature crop is damaged at a date beyond that of feasible replanting the potential loss is calculated from the expected yield per unit area and the price per unit yield. From this figure is taken the costs of farm operations, such as harvesting costs, not incurred. This method of calculating loss accounts for the fixed costs which still have to be borne by the farmer as they cannot be redeemed in the market place. The dates chosen as representing the cut off points of feasible replanting have been derived from Sanders (1958) and Duckham (1963). Studies of last planting dates have been carried out in the United States and equations indicating the financial losses incurred due to delay in planting have been determined by Mallett (1962). Reductions in yield caused by delayed planting could not be taken into account in this study due to the inapplicability of the equations determined in a different area for crops which differ to those in the Nith.

For flood incidents which occur before the latest date of feasible replanting the potential losses are calculated from the total of the variable costs that are incurred up to the date of the flood. The data used in calculating losses are taken from the West of Scotland College of Agriculture Economics Department publications by MacPherson (1966; 1967) and Reid (1969), the North of Scotland

College of Agriculture Farm Management Handbook (1971), Sanders (1958) and Duckham (1963)[1].

The potential losses by crop for each month has been made on the above bases and are given in Table 5.2 in which the crops considered are:

(i) <u>Cereal Crops</u> in which the data were derived from a sample of 38 farms in South West Scotland. The results from the 38 farms were averaged to produce an average figure for capital at risk per month per unit area. The last date of feasible replanting was considered to be April. Cropping was split between August and September.

(ii) <u>Root Crops</u> in which the data concerned potato crops, the principal root crop in the Nith. The data were derived from a sample of 23 farms in South West Scotland. The last date of feasible replanting was March. One quarter of cropping took place in August.

(iii) <u>Temporary Grassland</u> In calculating the capital at risk in this crop it was assumed that seed outlay is made in March, that fertiliser costs are spread throughout the

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[1] The data in these papers were considerably augmented by the results of confidential reports and advice given by sections of all three Scottish Agricultural Colleges. The author is grateful to these Colleges and must acknowledge in particular the help given by the West of Scotland College of Agriculture Economics Department.

growing season and that one third of the capital at risk is removed following hay and silage cropping in August. It was further assumed that the remaining capital at risk declines steadily until January.

Interest now returns to the use of these data in Strategy II. It will be recalled that in Strategy II assumptions are made. The first of these is totality. Essentially it is assumed that all of the capital at risk is lost if a flood occurs. This is determined from the equation:

$$FL = WMCAR \sum_{i}^{1} (A_i) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5.4)$$

The weighted capital at risk can be calculated from the data in Table 5.2 using Equation 5.2 with pj values for cereals, roots and temporary grassland of 0.215, 0.0225 and 0.7625 respectively. These results are shown in Table 5.3 below. From these data the mean capital at risk can be calculated to be £18.67. The flood losses for the Nith were calculated on this basis (Equation 5.4) and the results are shown in Table 5.4 for both the period of protection and for the 1960-1970 decade.

These estimates of loss derived from a damage basis show a marked reduction from those made from a loss basis. This is due mainly to the weighting made on the proportion of the floodplain area under each crop. If the Nith costing data are weighted in the proportions indicated in Table 4.6 the weighted mean capital at

Table 5.2 Distribution of capital at risk in £ per hectare for the three crops by month

Month	Cereals	Roots	Temporary Grass
October	2.26	82.80	9.10
November	11.98	0.95	6.90
December	11.98	2.09	4.70
January	13.90	2.09	2.50
February	13.90	2.09	0.00
March	14.95	60.00	4.52
April	25.10	109.37	7.22
May	93.88	113.53	9.92
June	94.23	331.20	12.62
July	94.39	331.20	15.32
August	94.39	331.20	19.02
September	47.18	248.40	11.30

Table 5.3 Calculated weighted capital at risk (£) per hectare per month using costing data specific to the study area

Month	WCAR	Month	WCAR
October	9.29	April	13.36
November	7.86	May	28.03
December	6.21	June	37.33
January	4.94	July	39.43
February	3.04	August	42.24
March	8.01	September	24.35

Table 5.4 Flood losses calculated using WMCAR and assuming totality

	Protected Period	1960-1969 Decade
Unprotected total flood area (hectares)	3,369	1,959
Protected flood area (hectares)	1,038	884
Reduction in inundated area (hectares)	2,331	1,075
Unprotected flood loss (£)	62,899	36,575
Protected flood loss (£)	19,379	16,504
Flood loss reduction (£)	43,520	20,070
Annual flood loss reduction (£)	1,892	2,007

at risk again approaches the value estimated for unit loss. The first point that must be stressed, therefore, is that extreme care must be taken when using loss estimates from apparently similar regions. Detailed attention should be given to ensuring the similarity of the distribution of enterprises in the area from which the estimate is derived and the area in which the estimate is applied.

It will be recalled that in the previous Chapter the concept of totality was demonstrated on the basis of damage estimates in the field to be of doubtful validity. Because of this the second Strategy was again applied but the concept of totality was rejected. Instead the estimates of flood loss were reduced by a damage factor which was set at 0.6. It will be recalled that in the floods of the North East of Scotland only 50 to 60 percent damage was estimated to have occurred despite the severity of the floods. The equation used to calculate flood losses thus became:

$$FL = DF.\ WMCAR\ \sum_{i}^{1} A_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5.5)$$

The flood losses calculated in this manner are given in Table 5.5.

The progressive refinement of flood loss estimation by introducing costing specific to the study area, by weighting the costings to represent the areas under each of the different crop types and by recognising that damage is often not total has resulted in an estimate, shown in Table 5.5, that is now approaching an order of magnitude lower than the estimates made in the first Strategy and reported in Table 5.1. However, the use of a damage factor in the above calculation of loss has involved making one of the following two assumptions: either that crops are not differentially damaged by flooding or that the crop distributions are similar in the Nith area and in the areas where the damage factors were calculated. Both of these assumptions have been shown by this study to be incorrect and it is finally necessary to refine Strategy II to take this into account. This can be done by introducing weighted damage factors (WDF). These recognise that different crops have been demonstrated to have different damage factors and that since these crops occupy different proportions of the Nith floodplain, a more accurate damage factor for the floodplain as a whole can be determined by weighting individual crop damage factors by the proportion of the floodplain they occupy through the equation:

$$WDF = \sum_{j}^{1} (DF_j \, p_j) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5.6)$$

Using the pj values discussed above and the mean damage to specific crops determined in Chapter IV a weighted damage factor was calculated. This had the value 0.328 reflecting the low $DF_j p_j$ value in the Nith area for temporary grassland of 0.183. Flood losses could, therefore, be calculated in a manner similar to that employed in Equation 5.5 using:

$$FL = WDF.\, WMCAR.\, \sum_{i}^{1} A_i \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5.7)$$

The loss estimates made on this basis are shown in Table 5.6. These estimates of loss are likely to be the most accurate that can be made for the Nith floodplain using annual data. However, since in Chapter II

Table 5.6 Flood losses calculated using a WMCAR and assuming a weighted damage factor of 0.328 (Derivation in text)

	Protected Period	1960-1969 Decade
Unprotected total flood area (hectares)	3,369	1,959
Protected total flood area (hectares)	1,038	884
Reduction in inundated area (hectares)	2,331	1,075
Unprotected flood loss (£)	20,651	12,009
Protected flood loss (£)	6,362	5,419
Flood loss reduction (£)	14,289	6,590
Annual flood loss reduction (£)	621	659

the months in which flooding took place have been determined this information is used in Strategy III. Before discussing Strategy III it should be noted that the loss estimates are now clearly an order of magnitude lower than those obtained by transferring unit loss estimates from other areas. The wide variation in the loss estimates that can be derived indicates that there is a need to make comparative assessments of different flood loss estimation methods. This need is emphasised by the lack of such work in the literature in both the urban and rural context.

5.4 Strategy III

In Strategy III the flood loss is estimated from the area inundated by specific floods and the weighted capital at risk for the month in which the flood took place. Again the flood loss can be calculated assuming totality, a damage factor of 0.6 and a weighted damage factor of 0.328 from Equations 5.8, 5.9 and 5.10 respectively.

$$FL = \sum_{m}^{1} (WCAR_m . \sum_{i}^{1} A_{im}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5.8)$$

$$FL = \sum_{m}^{1} (WCAR_m . DF. \sum_{i}^{1} A_{im}) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (5.9)$$

$$FL = \sum_{m}^{1} (WCAR_m . WDF. \sum_{i}^{1} A_{im}) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (5.10)$$

Table 5.7 below gives the weighted capital at risk by month for the Nith assuming totality, a damage factor and a weighted damage factor. From Chapter II the dates and areas of floods that would have occurred without protection and which did occur with protection are known and from these data the losses in each flood can be calculated and cumulated. This is shown for all three assumptions in Table 5.8 for the unprotected flood situation and in Table 5.9 for the protected flood situation. These results are summarised and compared in Table 5.10.

Table 5.7 Weighted capital at risk by month for the Nith floodplain assuming totality, a damage factor and a weighted damage factor

	$WCAR_m$	$WCAR_m$. DF	$WCAR_m$. WDF
October	9.29	5.57	3.05
November	7.86	4.72	2.58
December	6.21	3.73	2.04
January	4.94	2.96	1.62
February	3.04	1.82	1.00
March	8.01	4.81	2.63
April	13.36	8.02	4.39
May	28.03	16.82	9.20
June	37.33	22.40	12.26
July	39.43	23.66	12.95
August	42.24	25.34	13.87
September	24.35	14.61	7.99

Table 5.8 Flood losses (£) estimated for each flood in the Nith area that would have occurred without protection

Date	Inundated area (hectares)	FL (totality)	FL (DF)	FL (WDF)
January 1962	672	3,320	1,992	1,090
September 1966	312	7,597	4,558	2,494
August 1966	265	11,193	6,716	3,675
September 1950	265	6,453	3,872	2,119
December 1962	240	1,490	894	489
October 1954	240	2,230	1,338	732
January 1949	240	1,186	712	389
December 1953	189	1,174	704	385
September 1948	189	4,602	2,761	1,511
February 1948	167	508	305	167
December 1951	153	950	570	312
November 1946	71	558	335	183
December 1964	71	441	265	145
March 1952	59	473	284	155
April 1947	59	788	473	259
September 1960	59	1,437	862	472
November 1960	59	464	278	152
October 1967	59	548	329	180
		45,412	27,247	14,910

Table 5.9 Flood losses (£) estimated for each flood in the Nith area that occurred despite protection

Date	Area inundated (hectares)	FL (totality)	FL (DF)	FL (WDF)
January 1962	578	2,855	1,713	937
September 1962	153	3,737	2,242	1,227
August 1966	153	6,482	3,889	2,128
September 1950	153	3,737	2,242	1,227
		16,811	10,086	5,519

Table 5.10 Comparison of flood losses (£) under protected and unprotected situations (Data from Tables 5.8 and 5.9)

	FL (totality)	FL (DF)	FL (WDF)
Protection Period			
Unprotected flood loss	45,412	27,247	14,910
Protected flood loss	16,811	10,087	5,519
Flood loss reduction	28,601	17,160	9,391
Annual flood loss reduction	1,244	746	408
1960-1969 Decade			
Unprotected flood loss	26,490	15,894	8,697
Protected flood loss	13,074	7,844	4,292
Flood loss reduction	13,416	8,050	4,405
Annual flood loss reduction	1,342	805	441

This Strategy has indicated a further reduction in the estimated flood losses. This has happened because the protection works had the effect of removing a subset of the lower floods that occurred in those times of the year when flood loss would have been low due to the feasibility of replanting and thus only the variable costs incurred up to that point would be included in the costings. The floods that the protection works fail to prevent are those high floods which appear to predominate in the period from August to January. In August and September the capital at risk is at the highest point in the year and three of the four floods with protection occurred in this period. Thus the effect of protection works has been to reduce the number of floods that are unimportant both in terms of the areas they inundate and in terms of the time in the cropping cycle at which they occur. This study indicates that losses lie in the range from £400 to £1,250 per annum depending upon the assumptions made.

5.5 Strategy IV

Strategy IV explores the possible use of regression equations of the type examined in Chapter IV as a means of determining a damage factor for each field flooded. Since the model developed in Chapter II identifies which fields are flooded and since the land use in each field is known from the work reported in Chapter III it is possible to select for each field flooded in a specific flood a regression equation appropriate to the crop in that specific field.

If the regression equation can provide an estimate of the damage factors for each field flooded in a specific flood then the flood loss in each field, f, for a flood, i, can be determined from the product of the capital at risk for crop, j, in month, m, the damage factor for that crop, month, field and flood and the area of the field, A_f, thus:

$$FL_{if} = CAR_{jm} \cdot DF_{jmif} \cdot A_f \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5.11)$$

These results can then be cumulated by field and by flood to provide an estimate of total flood loss.

It is pertinent then to question the manner in which the values of the independent variables can be calculated for each field. The physical model determines the depth of water in each field for floods of specific sizes under different protection conditions. These values were commented on during the test of the model (Section 2.3.1.3). Depth is the variable that has most commonly been linked to damage in past studies. However, the results of Chapter IV indicate that although depth is important in the creation of damage many other variables are also significant. Because the months during which floods took place or would have taken place are known it is possible to determine the age of the crop at the time of flooding given knowledge of the local agricultural calendar.

Duration values for floods in some fields are known from diaried information of the Nith farmers. These values can be related to the flood depths calculated in the floodplain in the physical model. Durations of 12 hours are assigned to flood depths below 0.5 m and 110 hours to flood depth greater than 2 m. Durations of 40, 60 and 84 hours are assigned to the depth intervals 0.5 to 1, 1 to 1.5 and 1.5 to 2 m, respectively. Such a relationship has a physical basis in the non steady state drainage equations of, for example Glover Dumm (see Wesseling, 1973) in that for a particular floodplain typified by particular drainage characteristics the decrease in water level following the flood will relate closely to depth.

Chow (1964) notes that the type of flow occurring at any point within an area of overland flow depends upon such factors as discharge, viscosity and degree of roughness. If the detention depths are sufficient to produce persistent eddies then the flow is turbulent and the velocity can be expressed in terms of Manning's formula:

$$V = 1.486/_{n} \, R^{\frac{2}{3}} S^{\frac{1}{2}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5.12)$$

Chow further notes, however, that in overland flow conditions the hydraulic radius, R, may be replaced by the mean depth of the cross section. Since it will be recalled that in the physical model each field was assumed flat having a height equal to the mean of a number of spot heights it follows that the depth calculated for each field is a mean depth. Thus Z may be substituted for R. Slope was calculated from the difference in mean field heights between the field from which the floodwater is coming and the field under consideration. This figure was divided by the mean difference between field midpoints which was calculated to have a mean value of 200 m in the Nith floodplain. The roughness coefficient was set at 0.030. In cases where the slope calculations resulted in a negative value that is where the floodwaters are moving into a higher field, velocity is considered at the lowest value, 1. Where positive gradients exist the velocity is calculated through the above equation and is assigned the value of 2 when true velocity is less than 1.5 m s^{-1} and 3 for higher velocities. This corresponds to the relationship between true and estimated velocity in Chapter IV.

Using as appropriate one of the equations below, damage factors are determined:

Pasture DF = 2.1 Depth + 15.42 Velocity - 4.31 Age + 49.24 ... (5.13)

Cereals DF = 6.02 Depth + 15.68 Velocity - 5.89 Age + 48.46 ... (5.14)

Roots DF = 12.21 Depth + 0.138 Velocity - 6.40 Age + 64.6 .... (5.15)

For the period of protection it is estimated that unprotected flood losses would have been £14,922 and that with protection losses were £4,495, a reduction in loss of £10,427. The similarity of these figures and those calculated by weighted damage factors in Strategy III suggest that flood loss determinations derived from damages in specific fields and which therefore require extensive computing offer little improvement in flood loss assessment. Furthermore the calculation of the values of some variables are doubtful and for other variables known to be significant (for example sediment deposit) is impossible. In addition the exploratory nature of the work reported in the previous Chapters clearly leaves doubts concerning the efficiency of the regression equations themselves and it must be emphasised that this strategy is used only to explore the technical feasibility of this assessment method. It is interesting, however, that the results are so close to those of Strategy III. In this study it is accepted that the results of the third column of Table 5.10 are the most accurate representation of the flood loss to crops in the Nith floodplain.

For flood loss assessment in agriculture the critical aspects appear to be:

(i) the assessment of the flood area in specific floods,

(ii) the establishment of damage factors for specific crops, and,

(iii) the recognition of the importance of the time of the flood.

5.6 Protection Expenditure

The protection scheme was settled by the Secretary of State for Scotland in terms of section I(4) of the Land Drainage (Scotland) Act 1941. The Nith drainage scheme "is for the purpose of remedying and preventing injury by flooding and of improving the drainage of a total area of 2193.814 acres of agricultural land ....", DAFS (1942). However, an examination of the 19 works undertaken as part of the scheme indicates that the primary purpose of the scheme was clearly the prevention of flooding. None of the works were directly associated with drainage improvement. The cost of carrying out the scheme was estimated in 1942 to be £19,800 of which £5,716 was recovered from the Nith farming community. £5,716 was stated to be the total benefit expected to accrue to the lands in the area. If this is accepted then the Benefit Cost ratio from a public viewpoint would be less than 0.3 since all maintenance costs were to be paid by the farmers in the area. However, in this study it is assumed that the £5,716 represents benefits stemming from land enhancement. Since this money was to be directly recovered in the year of construction the net outlay was estimated in 1942 to be £14,084. By the time of their completion in 1946, however, the protection works had cost £41,000 and thus the real net outlay in the construction year was £35,290.

Consider now the maintenance costs. In the schedule of the scheme these were estimated to be a maximum of £330 per annum. The whole of this amount is recoverable each year from the Nith farming community in proportion to the area owned by individuals in the protected site. This reaches a maximum of £45.22 for the farm considered to receive the maximum protection. Yet maintenance costs over the three years 1968 to 1971 averaged £3,013. These were not "freak" years, similar calculations for 1965 to 1968 give an average of £5,494 due to the costs of repairs following the 1966 flood. Even removing the now token payment of £330 per annum the maintenance costs of c. £2,700 per annum are much in excess of the calculated annual flood loss reduction except for those estimated using Strategy I.

Reference to Tables 5.8 and 5.9 indicates that there has been no year in which the direct benefit stream (1970 prices) has exceeded the mean maintenance costs (1970 prices). Assuming sunk capital all strategies except Strategy I indicate a direct benefit to cost ratio of less than 1.

It is pertinent to question whether other significant benefits have been ignored. The enhancement benefit has been accepted as having a value of £5,716. It has been noted that the farm buildings are on raised hillocks and are not in fact damaged. It was recognised from interviews with the Nith farmers that some equipment was lost during and after flooding, but no farmer in the Nith estimated this component to be in excess of 25 percent of total loss. Similar National Farmers Union estimates following the 1970 floods suggest a figure of 20 percent (NFU files at Nairn). Thus annual loss reduction may be increased to c. £500 (Strategy IIIc estimate raised by 20 percent). It seems unlikely that a large amount of non agricultural damage occurs on the Nith for the following reasons:

(i) the model developed in Chapter II indicates that roads are only inundated at very high discharges (>1,000 m^3 s^{-1}), and,

(ii) the records of the local authorities do not indicate significant damage in the floodplain area.

In summary, therefore, accurate calculation of benefit under a sunk capital situation yields annual benefit figures of at least one third of annual costs. This study cannot recognise that intangible benefits are double the tangible benefits and therefore believes that from a public viewpoint there is little economic justification for the project. (From a private viewpoint the costs are merely the "token" payments of £330 whilst the benefits are at least £500 per annum).

However, this assessment of the protection works does not mean that the works necessarily fail economic tests as set under present DAFS policy. At present no strict cost benefit evaluation preceeds project approval. Instead a "worthwhileness" test is undertaken. This states that costs must not be <u>excessive</u> with regard to possible benefits. What constitutes excessive is not specified but in the author's opinion a cost that exceeds benefits is excessive. Possible benefits is a broad term to cover the expected change in land use, the value of which the reader will have noted is not included as a benefit. The rejection of land use change as a tangible benefit is discussed below.

5.7 Flood Insurance

Flood insurance has been examined in a general sense by Porter (1972). However, Porter at no time identified the annual basic premium necessary for flood insurance in any particular area. In the Nith area the total cost of flood loss to crops has been determined. It is therefore possible to suggest the scale of premium necessary to provide financial protection against crop flooding. It was shown in column three of Table 5.10 that total crop losses without protection would be in the region of £14,900. This indicates an annual flood loss of £648. The January 1962 flood covered some 672 hectares. If it is assumed that the flood risk is spread evenly over approximately this area, say 700 hectares, then the per hectare annual basic premium should be £0.93 or for a typical farm in the Nith of about 40 hectares an annual payment of £37.

However, interviews conducted during this study with the managers of insurance companies concerned in particular with covering various agricultural risks indicated that the administrative overheads associated with the basic premium to cover this type of risk would be high due to the small amount of business that could be expected to stem from the cover of flood risk to crops and due to the high expenditure made on calculating the flood risk in the first place. Estimates of the increase in premium required to run such a scheme ranged from 85 to 150 percent. Therefore, the premium payable by the farmer would be at least £62 to £92. However, this cost does not contribute to the establishment of a central fund. If the private sector were to establish flood insurance, the central fund would have to be covered by reinsurance. The insurers indicate that the cost of reinsurance would at least equal the capital recovery payments of a sum equal to the loss caused by the largest flood of record at the worst time of year. Table 5.10 indicates that the cost of the January 1962 flood occurring in August would be £9,321.

If a capital recovery factor is applied to this figure over a 50 year time horizon at a generous rate of interest of 12 percent, the annual payment by the insured in the floodplain would be £1,122. At a slightly more realistic rate of 15 percent the capital recovery factor would be 0.15014 (Kuiper, 1971) or £1,399. Using these data Table 5.11 indicates what might represent a realistic premium per farm to cover flood losses to growing crops. This ranges from £122 to £172. The premium to cover the residual risk calculated in the same manner is £103.

Table 5.11 Estimated cost (£) of insurance against flood loss per farm in Lower Nithsdale

		12%	15%
Basic premium		37.00	37.00
Administrative overheads	85%	31.45	31.45
	150%	55.50	55.50
Capital Recovery Payments		54.10	79.90
Minimum Cost		122.50	148.35
Maximum Cost		146.60	172.40

5.8 Land Use Change

In Chapter III it was found that there had been a change in land use in the study area and that the change in use was significantly different from changes in use observed in a similar area that had not been subjected to a change in flood risk. It should be noted that there is no method of determining what the land use would be at this present time if the area was unprotected. What is investigated in the land use that existed in the study area before protection.

Following protection the area under cereal crops was found to increase. The area under pasture declined and the bulk of the pasture was managed as temporary grassland. All of these changes increase the amount of capital at risk in the floodplain. However, it will be noted that the area covered by root crops was halved following protection. Since root crops have in fact a very high amount of capital at risk associated with them the overall result is to produce no effective change in flood losses. Calculation of the weighted mean capital at risk under the "old" system of land use using the same methods as were discussed above, yields a figure of £19.47.

This suggests that the land use changes that have taken place must be due to managerial convenience rather than economic rationality. In addition the fact that there has been no change in financial flood potential means that:

(i) the project cannot be justified on the basis of benefits stemming from land use change, i.e. from the protection of a more capital intensive crop or from the inducement of more profitable land use, and,

(ii) that the doubtful economic justification of the project cannot be explained by reference to unwarranted expansion of the intensity of floodplain use.

The effect of flooding and flood protection in an agricultural community has been examined in terms of:

(i) change in the frequency of inundation,

(ii) change in the extent of flooding,

(iii) change in land use and tenure, and,

(iv) change in flood loss.

At this stage it can be argued that the case study as such is complete. However, before drawing conclusions it is useful to attempt to generalise the case study with respect to time.

CHAPTER VI

A Generalised Assessment of the Flood Situation on the Nith

6.1 Introduction

In previous Chapters of this thesis the case study has been specific to time and place. The effect of flooding and protection on an agricultural community has been examined at a site in Lower Nithsdale for the period from 1946 to 1969. However, this period of time is unique in that it is unlikely that the same sequence of events will recur. Because of this there is a need to generalise the study with respect to time by examining the flood situation in the light of a flood frequency analysis.

6.2 Flood Frequency Analysis

Flood frequency analysis is widely used in hydrology and water resource management and is discussed in many publications concerned with these fields, for example, Chow (1964), Nemec (1972), Dalrymple (1960) and Harding (1972). In essence the analysis concerns the preparation of a curve which relates the magnitude of a variable to its frequency of occurrence. The curve is then an estimate of the cumulative distribution of a population of that variable.

Two kinds of frequency curve can be used for flood frequency analysis, the annual duration series and the partial duration series. In the annual duration series the peak flood in each year of record is used in determining the flood frequency curve. This method suffers from the disadvantage that infrequently the second highest flow in a year may be greater than a number of the annual floods. The partial duration series is not subject to this objection as all floods greater than a selected magnitude are utilised. However, the partial duration series can be criticised because it increases the possibility that some of the peak events may not be independent from each other. Langbein (1949) has shown that a clear relationship exists between these two series and that if a partial duration curve is required the United States Geological Survey method is to convert from an annual to a partial series using Langbein's relationship. Furthermore the annual flood method is statistically attractive due to its simplicity and the use of this method is widespread. In this study, therefore, the annual duration series is used.

The data for the analysis are taken from the continuous record at Friar's Carse. In addition all historic flows after 1910 having a stage greater than 4.634 m have been identified. The historic flows were identified in order to extend the record. The importance of a long record length has been demonstrated by a number of workers for example Benson (1960), Langbein and Alexander (1958), Nash and Amorocho (1966) and Glos and Krause (1969). Essentially the reliability of the estimate declines rapidly as record length shortens such that in a ten year record the error in the mean might be as great as 30 percent. Both the historical and record data have been discussed in detail in Chapter II.

The first step in the analysis is to determine the peak flow for each year of record and to check the independence of these flood events by examining the flow conditions prior to the event of interest. All of the annual peaks are found to be independent of one another. The next step in the analysis is to rank the flood discharges in order of magnitude and assign an initial order number to each flood. The order number one is given to the largest flood, two to the second largest flood and n to the nth largest flood. The flood of 1863, the largest known flood in the area is not included initially as there is no guarantee that the period from 1863 to 1910 did not include a flood greater than 4.634 m, in fact it almost certainly did include floods of over this magnitude. The 1863 flood is given the order number one for the 106 year period from 1863 to 1969. These data are given in Table 6.1.

The historical flood record contains all flood events of a stage of 4.634 m or over. If it is assumed that the lesser floods in the historic record follow the same distribution as the lesser floods in the period of continuous record the order numbers, and therefore the recurrence intervals for the annual floods in the period of continuous record, may be adjusted to the longer period for which the historical data are available by using the methods described in Dalrymple (1960). The formula used for the transformation of the order numbers is given in Equation 6.1 below.

Table 6.1 Calculation of plotting position for flood frequency analysis

Year	Peak Discharge (m^3s^{-1})	Initial order number	Final order number	Plotting position
1863	1416	1	1	107
1962	1275	1	1	61
1926	1062	2	2	30.50
1933	991	3	3	20.30
1930	885	4	4	15.25
1944	885	5	5	12.20
1940	868	6	6	10.17
1950	858	7	7	8.70
1966	815	8	8	7.63
1954	789	9	9	6.77
1949	780	10	10	6.10
1963	779	11	11	5.54
1953	755	12	12	5.08
1948	713	13	13	4.69
1910	713	14	14	4.36
1965	524	15	19.1	3.20
1960	487	16	24.2	2.52
1961	482	17	29.3	2.08
1968	464	18	34.4	1.77
1958	414	19	39.5	1.54
1967	410	20	44.6	1.37
1959	409	21	49.7	1.23
1969	383	22	54.8	1.11
1964	360	23	59.9	1.016

$$m_1 = A + \frac{(H - A)}{(T - A)} (m_0 - A) \quad \text{.........................} \quad (6.1)$$

where m_0 = the initial order number for all floods of record.

m_1 = the order number for the floods below the base of the historic record adjusted to the length of the historic record.

A = the number of floods equalling or exceeding the lowest historical flood.

H = the length of the historic record in years.

T = the total numbers of items in the array.

If the case of the first order number extension in the Nith data is considered it is seen that of the 23 items in the 60 year record, 14 are above the base of 4.634 m, thus H = 60, A = 14 and T = 23. From Equation 6.1, m_1, is calculated to be 19.1. The conversion of the remaining initial order numbers follows the same pattern and the final order numbers are entered in Table 6.1.

The final step in the analysis is to use the order numbers to determine the frequency of recurrence of these flood discharges. There are a large number of formulae[1] available for determining the

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[1] California (1923), Hazen (1930), Weibull (1939), Chegodayev (1955), Blom (1958), Tukey (1962) and Gringorten (1963). All of these methods involve artificial extension of the record with the exception of the California method which, however, is theoretically inadequate because it assumes that the lowest annual flood of record is the lowest annual flood possible.

recurrence interval. However, in this study the Weibull formula is used because it involves an insignificant record extension (1.67 percent) and remains theoretically acceptable as it allows for a lower annual flood than the lowest on record. The Weibull formula, sometimes known as the Geological Survey method because of its adoption by the U.S.G.S., is:

$$T = \frac{n + 1}{m} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6.2)$$

where T = recurrence interval in years

n = the number of years of record, and,

m = the order number of the flood.

The plotting positions for the Nith data calculated using Equation 6.2 are given in Table 6.1. These values are plotted against discharge on Powell (1943) paper using a logarithmic ordinate and the resulting frequency curve is shown in Figure 6.1. Plotting the line mathematically by the use of Beard's (1962) method yields no significant improvement on plotting by eye. The different types of plotting paper available are discussed by Benson (1960) and Harding (1972).

6.3 General Assessment of Flood Frequency Extent and Loss

The discharges that are of interest have been determined in Chapter II. These are the discharge at which overbank flooding commences and the discharge at which the levee is overtopped. These are estimated to have values of 435 m^3s^{-1} and 815 m^3s^{-1} respectively.

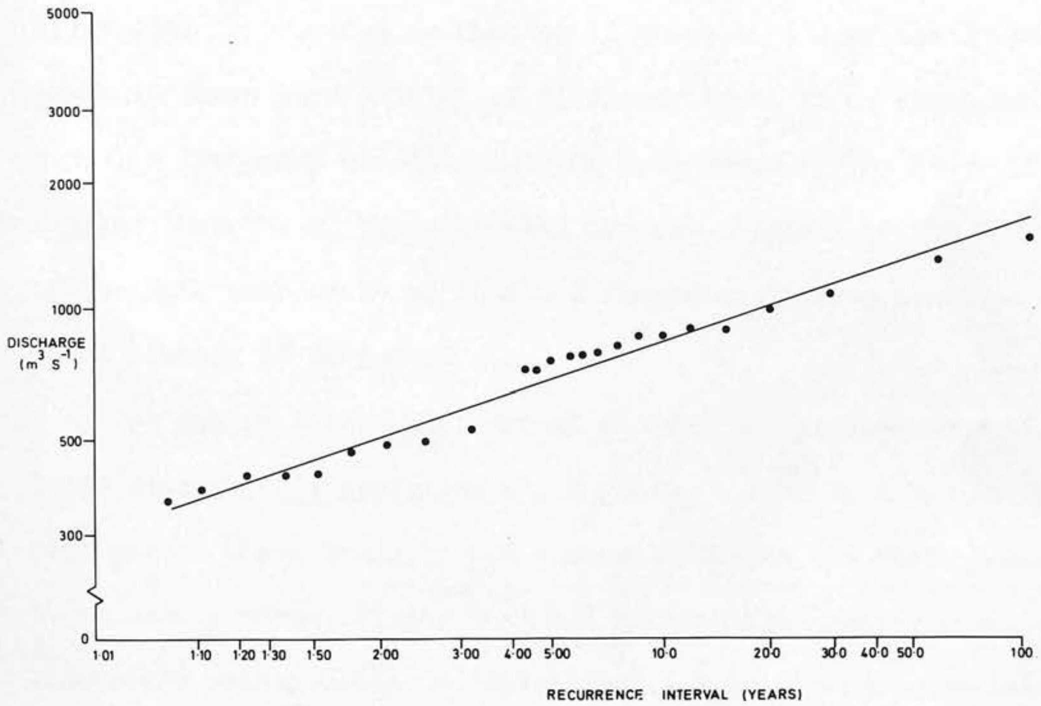

FIGURE 6.1 WEIBULL BASED FLOOD FREQUENCY CURVE FOR THE NITH AT FRIARS CARSE.

From the frequency curve it can be seen that the frequency of annual floods in excess of bankfull discharge is 1.30 years. Over the 23 years of flood history examined in the case study this suggests a total of 17.69 inundations. During these 23 years there were in fact 16 annual peak floods in excess of bankfull discharge. The use of the relationship developed by Langbein (1949) indicates that if the return interval of an annual flood is 1.30 years, its return interval measured on the partial series will be approximately 0.7 years. Reference to Chapter II shows that over the 23 years examined there were a total of 37 floods equal to or above bankfull stage, a frequency of occurrence of 0.62 years. The above figures suggest that the 23 years studied are not atypical of the flood regime of the Nith when compared to flood frequency figures based on a flood history of 60 years.

The return interval of annual flood flows greater than "levee full" discharge is approximately 9 years. Thus in a typical 23 year period there would be 2.6 floods. During the study period there were 3 annual floods that had a discharge greater than 815 m^3s^{-1}. Langbein's relationship indicates that a 9 year recurrence interval flood would have a partial series return interval of 8.5 years. This suggests that in the 1946 to 1969 period there would have been 2.7 floods greater than 815 m^3s^{-1} had this period been typical of the 60 years to which the frequency curve relates. There were 4 floods of this magnitude in the period studied. Again there is no basis to finding the frequency of flooding during the study period markedly atypical.

It is useful at this stage to examine the form of frequency calculation at present used by DAFS. It is believed that this might throw light on the reasoning behind DAFS present acceptance that from a public viewpoint the costs of continuing to upkeep the protection works are not excessive with regard to possible benefits. The analysis made concerning the original decision in 1942 to construct the protection works are not known. However, it is unlikely that a frequency analysis was carried out at that time as the continuous record at Auldgirth Bridge had existed for only 2 years. The argument presented here, therefore, concerns DAFS assessment of the present efficiency of the works.

In their assessment of flood frequency DAFS use a Hazen analysis. This is a form of frequency analysis in which the recurrence interval is determined from Hazen's (1930) formula in contrast to the Weibull formula used in this study. All other steps in a Hazen analysis correspond to those given in Section 6.2. The Hazen formula is:

$$T = \frac{2n}{2m - 1} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6.3)$$

The use of this formula on the data given in Table 6.1 results in the frequency figures that have been plotted in Figure 6.2. It will be noted that the effect of applying Hazen's formula to the data is to give a weighting to the high magnitude floods. Discharges that have been given the magnitude order of 1 are given a plotting position that is double the length of the record from which the flood is derived. Discharges of order number 2 are given a plotting

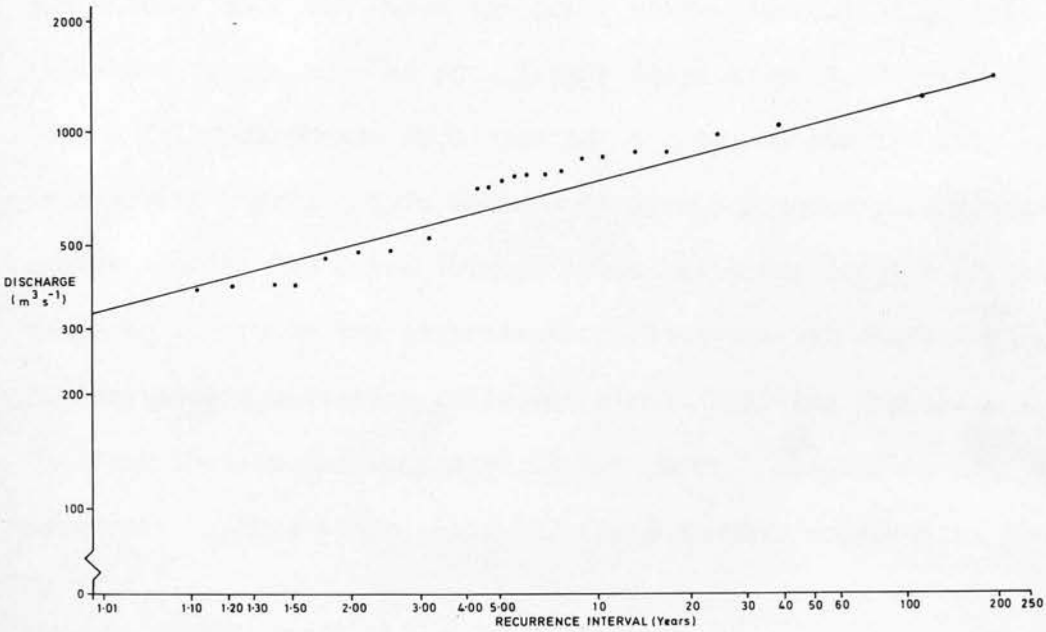

FIGURE 6.2 HAZEN BASED FLOOD FREQUENCY CURVE FOR THE NITH AT FRIARS CARSE.

position 33 percent greater than that determined by the Weibull formula. However, by order number 10 the artificial extension is a mere 3 percent. Essentially then low discharge inputs into the Weibull and Hazen analyses result in very similar estimated recurrence intervals whilst high discharge inputs result in large artificially extented estimated recurrence intervals in the Hazen analysis.

If the critical Nith discharges, bankfull and "levee full" are entered into the Hazen frequency curve, bankfull discharge is indicated to occur as an annual peak flood every 1.37 years but "levee full" discharge is estimated to occur on average only once in every 15 years. This means that from a frequency viewpoint analysis using the Hazen formula agrees with the results of this study in regard to the preprotection situation but under the postprotection situation indicates almost half the frequency of flooding that is (a) suggested in the general assessment of flood frequency in this study, and, (b) found to have occurred in 1946 to 1969.

Consider now the areas inundated by floods during the study period and the areas that would have been inundated during this period had protection not been available. The problem is to determine if the areas inundated in the case study are representative of the areas that are estimated by frequency methods to flood.

Since the areas inundated by floods of specific discharges can be determined by the model given in Chapter II and since discharges have been related to recurrence intervals in the second section of this Chapter, it is possible to relate area inundated to recurrence interval. This relationship is presented in Figure 6.3. The area inundated by a specific discharge differs under protected and unprotected situations and therefore two curves of area inundated against recurrence interval are presented in Figure 6.3.

A 50 year period is a common time horizon over which to assess the performance of a project. From the two curves presented in Figure 6.3 the total area that would be flooded both with and without protection over a 50 year period can be determined. This is done by summing the areas covered by the "perfect" series of recurrence interval floods from the 50 year flood to the 9 year flood in the case of the protected situation and from the 50 year flood to the 1.30 year flood in the case of the unprotected situation. The characteristics of a perfect series of recurrence interval floods have been discussed by Benson (1960) who examined a hypothetical 1,000 year record having one 1,000 year flood, two 500 year floods, three 333.3 year floods etc. This perfect series can be determined for any record from the formula:

$$T = \frac{N}{i} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6.4)$$

where $i = 1, 2, \ldots\ldots N$

N = the number of years of record from which the perfect series is required.

T = the recurrence interval

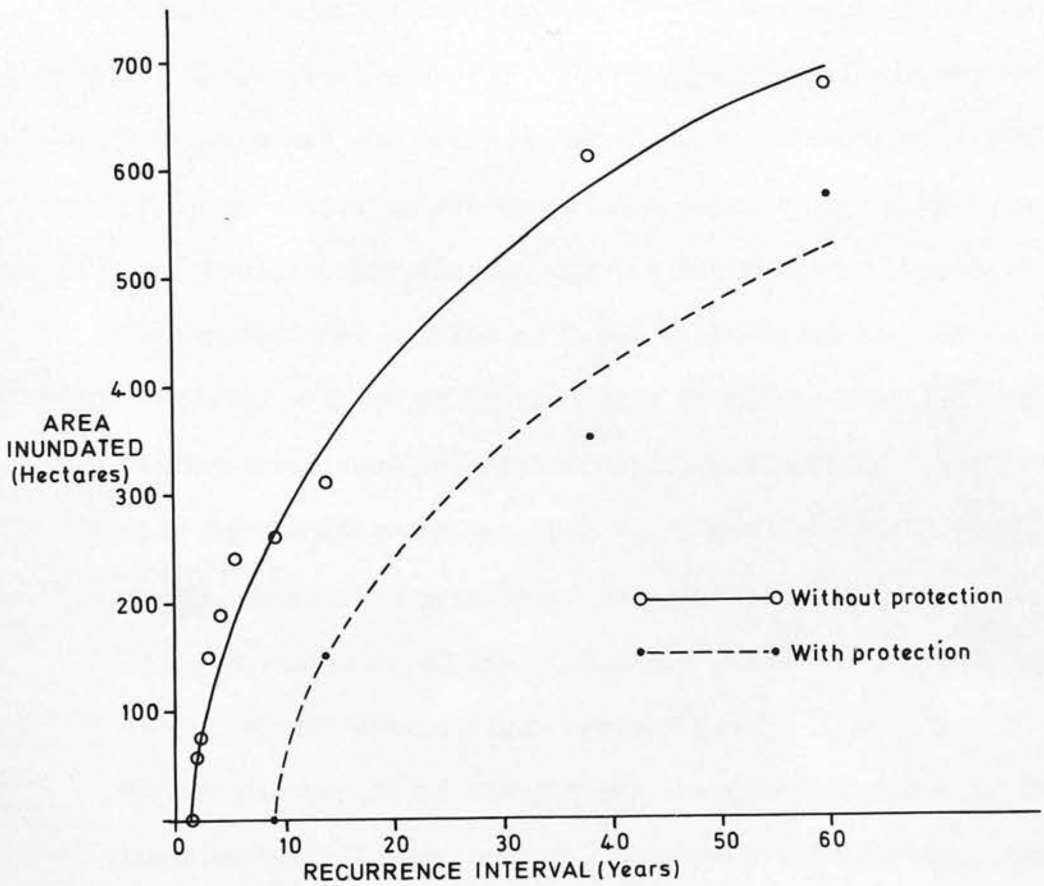

FIGURE 6.3 RELATIONSHIP BETWEEN RECURRENCE INTERVAL AND AREA INUNDATED. (WEIBULL BASED ANALYSIS.)

This formula results in one N year flood, two N/2 year floods, three N/3 year floods etc. In the Nith study N = 50 and therefore using the above formula the recurrence interval floods of interest can be determined. These have recurrence intervals of 50, 25, 16.67 etc. Clearly a 50 year record will have 50 floods in the series.

Summing the areas inundated by the floods of this series yields a total flood area for a 50 year period without protection of 6,100 hectares and for the same period with protection, 1,420 hectares. Flood area reduction in the 50 years amounts to 4,680 hectares or some 93.6 hectares per annum. During the period of the case study it is estimated that a total of 2,890 hectares of land would have been inundated without protection as a result of annual floods and that 884 hectares were inundated despite protection. The flood reduction in the 23 years has been 2,006 hectares or 87.2 hectares per annum. Again the results of the general assessment, 93.6 hectares flooded per annum, and of the case study assessment, 87.2 hectares flooded per annum, are in close agreement.

In the discussion of the general frequency of flooding the use of the Hazen analysis by the DAFS was introduced. It seems useful to examine the generalisation of the flood area estimates in the same manner by determining the effect of applying a Hazen based analysis. In this study no evidence has been found to suggest that the DAFS has in fact related area inundated to recurrence interval using any form of frequency relationship, consequently no evidence has been found to indicate any attempt to use such data to determine the differences in inundated areas with and without protection. The rationale of examining Hazen based total inundation area estimates is that Hazen analysis used by DAFS. It is a logical step in the assessment of a flood protection project to determine areas inundated on the basis of frequency curves and therefore it is of interest to look now at a Hazen based analysis for this seems the likely form of analysis that DAFS would use should they analyse future projects or retrospectively assess the values of their present projects.

Figure 6.4 shows the relationship between flood area and recurrence interval determined by the methods outlined above but using as a basis the Hazen frequency curve, Figure 6.2. From these curves the total areas inundated by the perfect series of recurrence interval floods over a 50 year period with and without protection are determined. With protection 480 hectares of land are estimated to flood in a 50 year period. Without protection 4,175 hectares are estimated to flood. The Hazen based area analysis has reduced flood area with protection to 0.34 of the Weibull based area estimate whereas it has reduced the flood area estimate without protection to only 0.68 of that estimated by Weibull based analysis. Thus the effect of Hazen relative to Weibull is to reduce the apparent severity of the flood situation as a whole and to emphasise the reduction in the flood area caused by protection. However, the reduction in flood area with and without protection is 3,695 hectares or 73.9 hectares per annum when determined from Hazen analysis as opposed to 93.6 hectares per annum from Weibull estimates. Thus the overall effect of Hazen based analysis is to reduce the apparent benefits of protection.

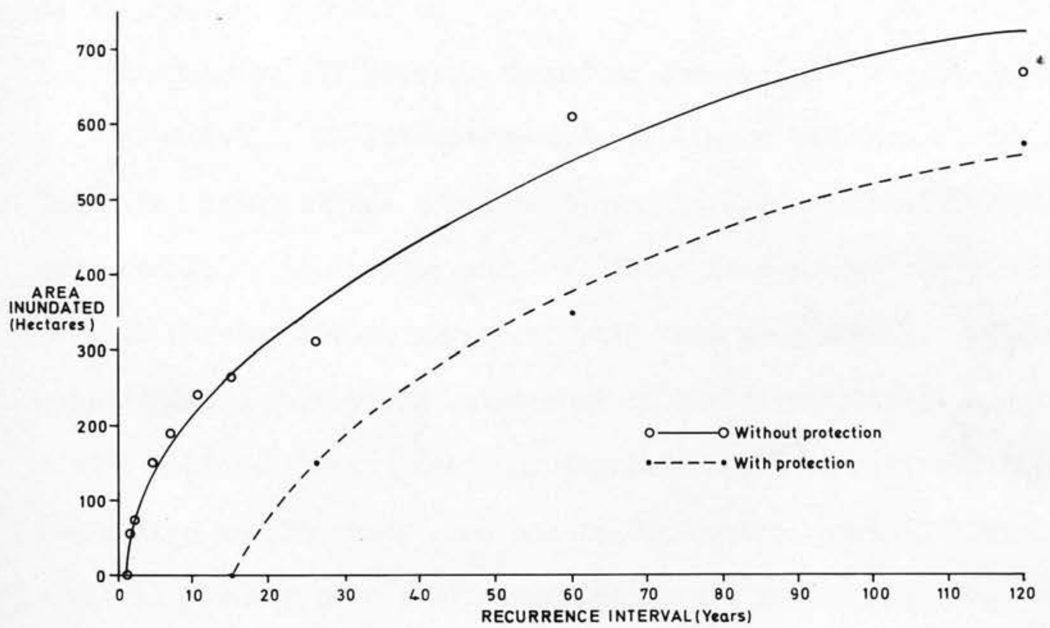

FIGURE 6.4 RELATIONSHIP BETWEEN RECURRENCE INTERVAL AND AREA INUNDATED. (HAZEN BASED ANALYSIS.)

The generalised estimates of the changes in the frequency of flooding between the protected and the unprotected situation differ under Hazen and Weibull analysis. Although it has been demonstrated above that this has a direct effect upon any assessment of a project through, in the case of the Hazen analysis, reducing the numbers of floods expected to occur with protection and therefore reducing the total area expected to flood with protection it may also have the significant indirect effect of suggesting major land use changes as a result of protection.

In Chapter III possible land use changes as a result of protection were examined. In attempting to establish a theoretical basis for land use change it was noted that considerable residual hazard remained following protection, one flood in 6 years (the results of this Chapter are in agreement with that assessment). However, questionnaire survey indicated that in the farmers' view there was little residual hazard (see Chapter III) and a comparison of land use change in the study area and in the control area indicated that there had indeed been a differential change in land use following protection but that the change in land use had little financial significance in relation to flood losses. The use of a Hazen analysis would indicate that after protection there would be no significant flood risk, one flood in 15 years, compared to the previous very high risk situation of one flood every 1.37 years and therefore a very significant change in land use might be expected. It is reasonable to suggest then that Hazen analysis not only gives unwarranted emphasis to the direct benefits of protection but also gives unwarranted support to expectations of land use change.

Finally, in this Chapter it is necessary to generalise the financial aspects of the study. It will be recalled that in the previous Chapter both strategy three and strategy four made use of data specific to the flood: namely, the month of occurrence. However, in a generalised assessment the month of occurrence is not known and therefore strategy two is the only applicable financial strategy. Bearing in mind the effects of the different strategies presented in the last Chapter, this restriction clearly represents a strong argument in favour of a case approach to the study of agricultural flood damages as the effect of the season is so important in the rural context as to make generalised assessments of doubtful applicability.

The second strategy relates area inundated to loss using the mean weighted capital at risk. Since Figure 6.3 correlates area inundated with recurrence interval it is possible to relate flood loss to recurrence interval. This relationship is presented in Figure 6.5. Since three assumptions concerning totality, damage factors and weighted damage factors were made in the second strategy, Figure 6.5 shows six curves indicating the relationships between flood loss and recurrence interval for both protected and unprotected situations under these three assumptions.

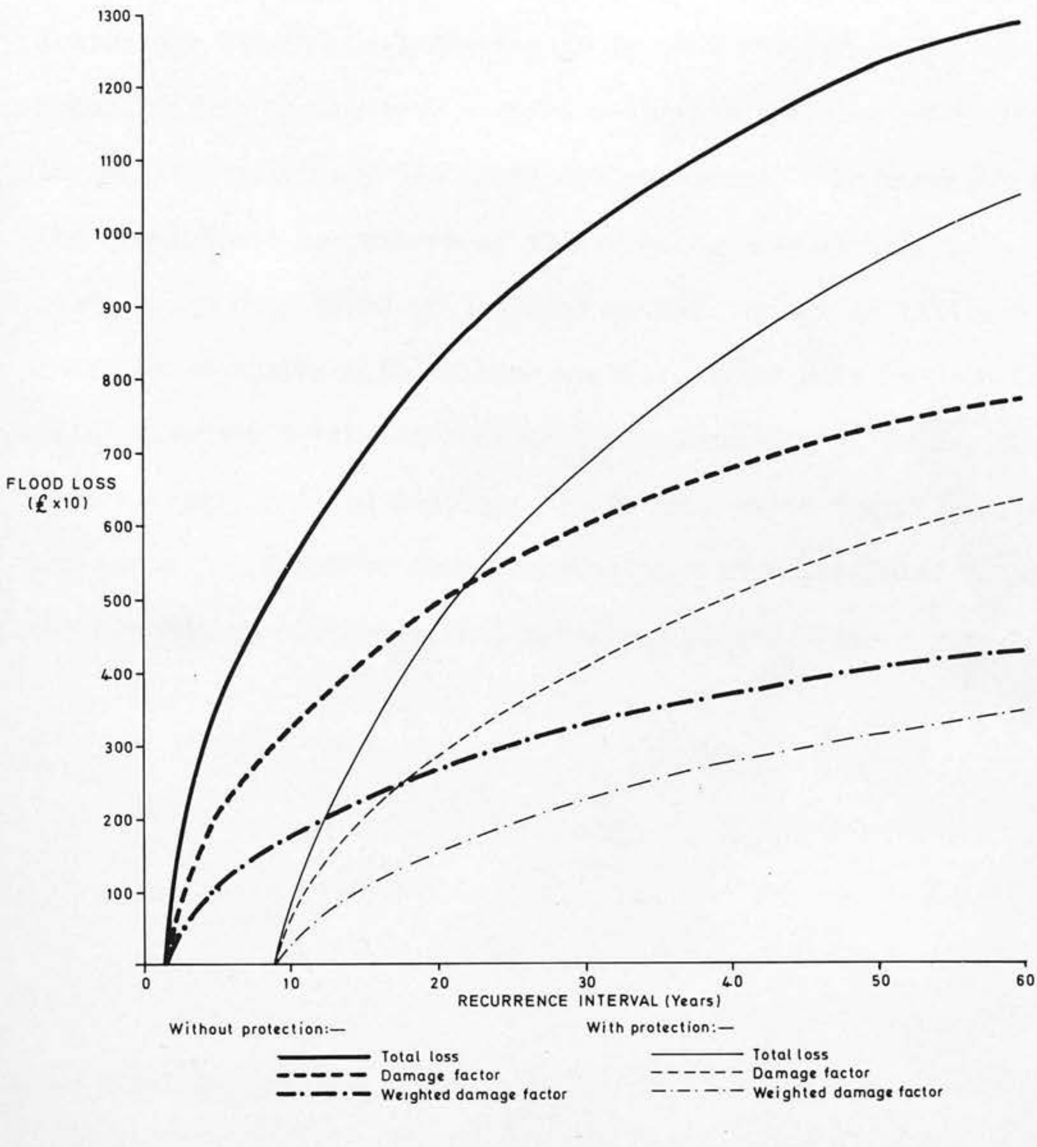

FIGURE 6.5 RELATIONSHIP BETWEEN FLOOD LOSS AND RECURRENCE INTERVAL, BOTH WITH AND WITHOUT PROTECTION, USING ASSUMPTIONS OF TOTAL LOSS, A DAMAGE FACTOR AND A WEIGHTED DAMAGE FACTOR.

Once again the perfect series of recurrence interval floods can be used as an input to Figure 6.5 and the total losses over 50 years calculated. Consider the difference between protected and unprotected flood losses assuming totality. Without protection the expected losses are £113,887. With protection the expected losses are £26,511, a reduction in loss of £87,376 or £1,748 per annum. This figure compares favourably to the case study figure derived from strategy IIa of £1,892 per annum. In summary, therefore, the generalised assessment of flood loss agrees closely with the case study assessment based on the same method but the inability of a generalised approach to utilise month specific data is seen as a major drawback to any agricultural flood study that is not based upon a specific flood history. With respect to the frequency of, and areas inundated by flooding, the case study is found to be representative of the general situation on the Nith.

CHAPTER VII

Conclusions

In the concluding paragraphs of the majority of the Chapters of this thesis brief conclusions relating to the subject considered in that Chapter have been made. It seems appropriate to gather these conclusions within this final Chapter and in addition to consider shortcomings in both research techniques and objectives. In common with most other items of research work this thesis identifies more areas requiring study than it clarifies and therefore following the statements concerning conclusions and shortcomings, recommendations for future research are made.

Perhaps the most important facet of this work is the demonstration that even in an extremely flood prone area the assessment of the physical and economic effects of a protection scheme cannot be made on the basis of a questionnaire survey, or on the basis of published work. It is found in this study that basic information on flood frequency, area and loss is not systematically recorded and that assessment methodology is ill-developed towards operating in such a data poor environment.

It is now becoming widely accepted that in a flood study in which the effects of a change in flood hazard are examined the study should consider the "with and without" situation rather than the "before and after situation". (See Brown, Contini and McGuire, 1972). There are both empirical and academic reasons for this viewpoint. Flood studies cannot be made over a short time period.

In cases where the flood risk has been reduced to one flood in 10 years, a study period of say 5 years is likely to result in a non-representative assessment of the flood situation. However, if a long post-protection period is examined it is necessary to examine a similar period before protection. Since the research worker could easily be involved in attempting to estimate flood characteristics 20 to 40 years previous to the time of the investigation and since this case study finds that data on even relatively recent floods are often incomplete it is clear that empirical data problems beset any "before and after" study. Academically such investigations are of doubtful validity due to the possibility that the two periods of study are dissimilar from either a hydrological or economic viewpoint.

Studies of the "with and without" situation are conceptually sounder. However, since either the with or the without situation is hypothetical, that is protection either exists or does not, the research worker is always faced with at least one flood situation that can be assessed only through detailed studies of the flood regime and the floodplain. This study indicates that in fact due to data paucity both flood situations have to be analysed in this manner. The physically based mathematical model is found to identify the areas flooded with over 90 percent accuracy in the case of a flood having a recurrence interval of 60 years (Weibull analysis). It is believed that models of the form discussed in this thesis are necessary if progress on flood hazard evaluation is to be made. However, the model can be criticised on the relatively large amount of basic data that are required to define adequately the characteristics of the floodplain. It is suggested, therefore, that a subject for future research is to determine whether data adequate to produce accurate results can be derived from photogrammetric sources. A further topic for future research is to examine the general applicability of this model. The model should be applicable in any floodplain where the volume of overspill can be estimated and where the physical structure of the floodplain can be measured.

This study finds that following protection residual flood hazard exists. Although it is recognised that there will always be residual hazard following any flood control project it is noted that in this case the hazard has not been reduced to low levels as defined in Burton's (1962) agricultural flood hazard classification but remains at the intermediate hazard level. It is likely, therefore, that the possible changes in land use practice following protection in the area are modified by this residual hazard and thus land enhancement values and flood potential may not rise to the same extent as might be expected had the flood hazard been reduced from high to low levels (again on Burton's classification).

An examination of past studies which have sought to determine if changes in flood potential occur following protection in agricultural areas and of studies concerned with the rate of diffusion of an innovation suggests that in the past changes have been sought over too short a time period. However, it is recognised that merely to examine change over a longer time span is unacceptable because any changes in use may be attributed as validity to changes in market circumstances as to change in flood hazard. This study considers it necessary to control such an examination of land use change by determining whether or not the changes in land use differ significantly from the changes in use in a control area which has not been subject to a change in hazard but which has the same physical and economic environment. The results of investigations made on this basis show that there is a differential change in use that can be supported by logical and statistical analysis. However, criticism can be levelled at this section of the study in that it fails to examine the changes in land use throughout the period of study. It is recommended, therefore, that government sponsored survey based studies should follow the relative changes in land use over a significant part of the life of a project. Furthermore, it is recommended that similar studies should be undertaken at sites where the protection scheme is sufficiently effective to reduce the flood hazard from high to low level.

At the most tentative level this study finds that there is evidence to suggest that the form of land tenure might be selected so as to provide economic protection against flooding. This study indicates a clear need for further work to be conducted to determine whether or not such a form of protection exists and if so to elucidate the mechanisms by which it operates. In common with other studies of flooding it is suggested that the magnitude of flood loss and the amount of public investment made on flood alleviation are data which are not known on a national basis and which clearly should be available. If it is demonstrated that one form of flood alleviation is through multiple holdings and flood damage tax deduction this would of course represent a further source of public payment which should be included in any national assessment of flood alleviation expenditure.

It is convenient to the analyst to assume that agricultural flood losses are always total and on first appraisal the relatively low value of capital at risk per unit area might suggest that such an assumption would not lead to extensive error. However, during floods large areas of agricultural land are inundated and in total assumptions of complete loss are as unjustified in the rural context as they are accepted as being unjustified in the urban context. In this study an examination of damage to crops shows that in the majority of cases damage is not total and is seen to range from no apparent damage to total damage to the crop. It is found on the basis of the survey undertaken in this study that mean damage is approximately 60 percent of total damage.

White (1964) shows that in urban flooding damage to a structure depends upon the type of structure that is flooded and upon the characteristics of the flood. Similarly, in a rural context it might be expected that different crops would have varying proneness to damage. A comparison of the damage suffered by the different crops examined in this study suggests that these variations in flood proneness do exist. The flood characteristic most often related to damage is depth, see for example White (1964), however, the results of the Scottish study indicate that although depth is an important damage related variable it cannot be used as a definitive predictor of damage especially at low flood depths. This study finds that a number of other variables, e.g. velocity, age, proportion submerged, are at least as important as depth in the creation of flood damage to crops. Unfortunately many of these variables are difficult to determine accurately in the field and prove to be yet more difficult to predict in the floodplain. None the less this study must emphasise that despite the convenience of depth as a damage related variable it is not the sole variable of importance in agricultural flooding.

An examination of the damage suffered by individual crops indicates that the relative importance of different damage producing variables changes within crop types. For example, in cereal crops duration is found to be of little apparent importance whereas in root crops duration is believed to be an important variable. Within the cereals category it is found that the proportion of the crop submerged is significant only in barley crops. Such a result is in agreement with the findings of controlled environment research workers such as Heide, Boer-Bolt and Raulte (1963) and Greenwood (1967).

In an attempt to clarify these intercorrelated data and in the hope that depth could be shown to be the important underlying variable factor analysis has been applied. This allows a logical interpretation to be made from the data but confirms the result that depth is but one of a number of important variables. The interpretation of the data is that there are two principal sources of flood damage. The first is derived from the erosive force of the floodwater, its power to uproot, bend and break the growing crops.

The second source of damage is what has been termed in this study, the biological component of damage. It is believed that the biological component becomes significant only if the initial impact of the floodwater is sufficiently low to leave any crop to be biologically damaged.

Perhaps more than any other part of this study this Section which has looked at variations in flood damage and the causes of this variation can be criticised and can generate many avenues of future research. That it was necessary to embark upon this Section of the study is in itself an indictment of past flood research especially at government level. In the United States the Soil Conservation Service (USSCS) has collected data on agricultural floods. These data have been used to provide damage factors by crop types for each month at one foot increments. No equivalent data exist in the United Kingdom from which damage factors can be estimated. It is clearly not the role and is out with the normal resources of a University scientist to collect data after a sufficient number of flood events such that by data subdivision procedures, as used by the USSCS, damage factors for all crop types can be determined. However, this study has thrown light on the measurement and application problems associated with what are believed to be some of the key variables. This study strongly recommends that data which could be used in the study of damage factors be collected, as and when the opportunity is presented, by those official and semi-official bodies (DAFS, MAFF, NFU, the Agricultural Advisory Services) which have an interest in such data. It is clear that to be of value these data must be comparable and for the purposes of calculating damage factors the results of this study suggest that the following observations be sought:

(i) the estimated percentage damage to the crop. Where possible this value should be checked by market receipts,
(ii) the type of crop,
(iii) the date of planting,
(iv) the date of the flood,
(v) the stage of crop development,
(vi) the maximum depth of the floodwater,
(vii) the duration of the flood,
(viii) the proportion of the crop submerged, and,
(ix) whether the flood involved flow by hydraulic slope or by topographic slope, i.e. is the flow caused by the depth of water increasing and forcing water upslope or is the flow downslope.

It should be noted that in the above list of recommended observations one of the variables measured in the Scottish study is rejected whilst a second is severely modified. The rejected variable is sediment deposit. Although the results of the single variable analysis suggest that sediment deposit is significantly associated with damage this variable is difficult to measure satisfactorily in the field and is at the present state of knowledge unpredictable at the flood site. The modified variable is velocity. The suggested use of a new form of measurement is made for the following reasons.

Data subdivision and comparison indicate that velocity is an important damage related variable. However, the prediction of estimated velocity is difficult. Firstly, because the relationship between true and estimated velocity is likely to hold good only in the region where the estimate is made because such an estimate is clearly related to the velocities that the estimator has experienced. Secondly, in predicting velocity in the floodplain the choice of Manning's 'n' is much more complex than in the channel because n will vary at least with the type and age of the crop. Measures relating to the form of flow are easier to determine in the field, are more readily predictable from topographic data of the type used in the second Chapter of this thesis and are more amenable to analysis using dummy variables.

The study indicates that considerable variation in the estimates of loss occur due to the choice of assumptions that can be made in the assessment. These variations are likely to have been greater had not the study given detailed attention to the assessment of the changes in flood frequency, area and potential. The growth in public expenditure especially in the post-war period (discussed by Peacock and Wiseman, 1967) suggests that there is a need to adopt a rational approach to resource allocation and to question the efficiency of expenditure through some form of benefit cost analysis as discussed in Haveman (1972) and Prest and Turvey (1965). This study finds that under all but the most naive assumptions it is not possible to justify the public expenditure made on the Nith scheme.

If the standard procedure of determining the net costs or benefits at the end of each year is used, it is estimated that benefits do not exceed costs in any one year. Therefore, even without the use of a discounting technique (and the reader will recall that a large expenditure was made at the outset of the Nith protection project) the benefit to cost ratio is infinitely small. In common with objective studies by American authors (Krutilla, 1966; Clarenbach, 1958; Wolman, Howson and Veatch, 1953; Leopold and Maddox, 1954; and House of Representatives, 1952), this study finds that project costs are underestimated and benefits overestimated to the extent that the project fails financial analysis.

It is difficult to find any arguments which can relieve the gloomy financial assessment of the project made in the study. The distribution of the benefits of the project are inequitable in as far as they are directed almost exclusively towards a relatively small number of people in essentially private industry. The fact that in its original conception the estimated maintenance costs of the project were intended to have been totally paid by the beneficiaries indicates that DAFS viewed the project as essentially private (given impetus perhaps by a public body). This being so, had a benefit stream emerged to be discounted, it could be argued that a market rate of interest, say the gilt edged rate, would have been a more appropriate interest rate than a lower social time preference rate. Again this suggests that the project is economically ill-conceived.

This study finds that a potentially more effective method of protection, from the public viewpoint, is through insurance. An issue that has been discussed in Kenreuth and Shaeffer (1970) and Hempsell (1962). Insurance, of course, would have the additional zoning advantages indicated in Hoyt and Langbein (1955). However, the availability of flood insurance to growing crops is found in this study to be effectively zero despite the comments made in the Policy Holder (1961) and in the House of Commons (1961) regarding the ease of gaining flood cover:

> "Everyone who has property at risk should in ordinary prudence take his own precautions and should consider the importance of insurance."

This study finds little financial basis to the changes that are believed to have occurred in land use due to protection. Krutilla (1966) has argued that many projects are economically doubtful because the benefits are costed on the basis of expected increases in property prices and capital at risk which often do not materialise. This study agrees with Krutilla's findings.

Frequency analysis indicates that both in terms of the frequency and extent of flooding the case study is representative of the flood regime of the Nith. However, in terms of agricultural loss assessment it is clear that because of the annual variations in the susceptibility of crops to damage and because of the annual variations in the capital at risk methods which use general frequency assessments cause considerable loss of information. Hazen based analysis is found to artificially improve the "efficiency" of the protection scheme and it is suggested that a summary examination of the efficiency of the scheme based on this frequency method might indicate continued support of the scheme.

The study of extreme hazards is one in which observations must be "opportunist" and made under difficult conditions. In addition it must be recognised that data derived from interviews with people involved in the hazard situation are open to criticism due to the possibilities of obtaining biased replies. For these reasons the study of natural hazard must be considered an inexact science yet the importance of hazard in monetary and human terms indicates that despite the problems associated with measurement, the subject should not be neglected nor should it be pursued at a theoretical level to the exclusion of field observation. The author hopes that the work reported in this thesis will add to the body of knowledge concerning the flood process.

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APPENDIX 1

1. The Study Area

- Climate and Weather
- Geology
- Topography
- Soils
- Vegetation
- Land use
- Stable Basin Characteristics
- Protection Works

THE STUDY AREA

Climate and Weather

At present there are no meteorological memoranda for the study area. The climatic account given here is therefore based upon studies of the surrounding regions, together with the records of the stations at Lowther Hill and Leadhills and the rainfall at a number of stations including Moniave, Dumfries, Glen Afton and Green Burn.

In general, the approach and passage of North Atlantic depressions controls the wind regime of the district. The area falls within the main path of major systems on many occasions, except when the flow follows an Icelandic pattern. Although this is the dominant weather regime of the region, high pressures centred in northern latitudes tend to recur in the first half of the year, causing an opposite synoptic effect. The wind rose from the Lowther Hill station at the eastern boundary of the catchment showing a predominance of westerly winds, accounting for 55 percent of the annual total, mainly in summer and autumn. During the winter, easterlies are dominant whilst in spring most wind vectors are represented.

Moderate to fresh winds (21-39 km per hour) occur on 45 percent of occasions, double that of the frequency of strong winds (40-45 km per hour). Gales in winter occur about 9.5 percent of the time, but the annual rate is about half this figure at 5.5 to 6.0 percent. Gales occur on about 100 days in the year and in all months except

April, July and August gusts of over 140 km per hour have been recorded. Gusts of over 193 km per hour have been recorded in the study area. This is the free air wind regime taken from the only wind recording site in the basin, it must be borne in mind that the wind regime of most lower sites will be greatly affected by topographic features, they will, however, remain a function of this basic flow pattern.

Over much of the study area the rainfall is some 1,200-1,400 mm, but may reach 2,500 mm at the highest altitudes, Afton Filters (388 m) receiving 2,114 mm (mean 1,916-1,950), a similar amount, 2,128 mm, at Montraw (418 m) and at Green Burn (431 m) over 2,320 mm. Autumn and early winter are the wettest periods of the year, 45 percent of the rain falls in the four months from October to January. February shows a marked drop in precipitation symptomatic of the continued decline in the amount of rainfall through to May. From this month rain increases towards its mid-winter maximum.

Days of measurable rainfall (+ .25 mm) occur on about 200 days a year but this figure will be more in the region of 250 days in the higher altitudes of the catchment. The number of wet days (+ 1.01 mm) is between 165 and 180 days, but again at greater altitudes more wet days will occur, for instance at Leadhills the figure is 190 and tops 200 at Lowther Hill.

In the study area snow is usually the result of polar depressions moving south-east from the north of Ireland. At sea level, a little over 2 percent of the annual precipitation falls as snow, this figure rises to some 14 percent at above 330 m. Lowther Hill has about 64

(64.1) occurrences of falling snow per annum, whilst Leadhills has about 43. At this site snow lies for 46.9 days per annum on average. Above 400 m snow may lie for two months.

The range in mean temperature per annum is in the region of 6°C, although this figure may be greatly affected by topography. At about 330 m there are some 100 frost days a year (Leadhills 97), and again at greater altitudes the frequency will be higher, 147 on Lowther Hill. The growing season (daily mean temperature greater than 5.6°C) is approximately 210 days at 150 m dropping to about 190 days at 365 m. At sea level the growing season is some 230 days. Annual evapotranspiration for the north of Dumfriesshire is calculated to be 420 mm of which approximately 85 percent occurs in summer. In the high rainfall months 66 mm of evapotranspiration is calculated to occur. Mean monthly sunshine values fange from 20 to 27 hours in December and January to 150 hours in June and July.

Hail and thunder are of little importance in the study area. Records at Lowther Hill show six occurrences of each per annum, and at Leadhills seven occurrences. To a limited extent these phenomena appear to be mutually exclusive in the study area. Thunder predominates in the summer months.

The incidence of occult precipitation can be closely correlated with locality and height. For example, at Lowther Hill 228 days of fog (fog seen at 09.00) are recorded per annum but at Leadhills only 8.7 occurrences are noted per annum. Although the contribution of this occult precipitation to ground moisture may be great at high elevations, at lower altitudes it drops to an almost insignificant level (from a flood hydrology standpoint).

Geology

The Nith basin consists mainly of Lower Palaeozoic rocks, shales and greywackes of Silurian and Ordovician period, highly folded rocks which form the main upland areas of South Scotland. The Silurian band lies south of Thornhill and runs to the sea. The Ordovician is to the north of Thornhill and continues to the north until it is limited by southern uplands fault, a major fracture which crosses the study area in the region of New Cummnock. The headwaters of the Nith lie in this area of Ordovician to the south but in the north they flow from the igneous volcanic and intrusive rocks of the fault. The river runs along the fold axis of the Dumfries, Thornhill and Sanquar basins, small areas of younger rocks. The Dumfries basin is of new red sandstone bounded by hills of Lower Palaeozoic greywackes. Breccias composed mainly of greywackes and porphyry fragments from the Caledonian Dykes, with subordinate sandstones occupy the western part of the basin. The Sanquar and Thornhill basins are composed mainly of coal measures, millstone grits, carboniferous lavas, new red sandstones, carboniferous limestone and calciferous sandstone. Much of the floor of the Nith is composed of soft Upper Palaeozoic sediments, and some of the headwaters of the Clyde flowing on indurated Lower Palaeozoic sediments have succumbed to the regular encroachment of the Nith. The Dinabid Linn near the Dalveen Pass is a captured stream of the Clyde and in fact the Nith has become the long river it is today by this process of integration.

Topography

The catchment is bounded by hills which at their lowest point, at the Black and Creoch Lochs in the north of the study area, are some 200 m in elevation. To the east and north east the catchment is bounded by the Lowther Hills, culminating in Lowther Hill itself at 725 m which is the water divide between the Nith and the Clyde, the Nith watershed lying to the west of the hills and the Clyde to the east. To the west the study area is bounded by un-named groups of hills.

The watershed rises sharply from 20 m on the floodplain to over 300 m at Auchencairn Height 5 km distant. It remains at this level for about 7 km and then climbs steeply to Gana Hill (668 m). From here the boundary goes to the north west, for over 20 km fluctuating between 518 m and 655 m. A slow drop in height commences at Wanloch Dod and continues through Windy Dod where the boundary shifts to the westward before rising to Wedder Dod, the most northerly point of the catchment (NS760216). At Carsgailloch Hill the watershed turns to the south, having passed its most westerly point at Benbain (NS505095). The boundary turns towards the east once more 1 km to the west of Pickerny Hill, the source of the Nith, and then south east at about 550 m until it reaches Mullwhanny Hill (535 m). From this point the boundary drops to 330 m in the Keir Hills and then finally falls by 300 m in 10 km to the floodplain.

All aspects are represented in the study area, but the area of northern aspect is the smallest. East and west aspects are the most common. Slopes within the catchment are extremely varied. In the floodplain area slopes are slight, whilst in the upland regions extremely steep slopes can be encountered. Typical examples of the steeper slopes are found at Knockenhair, 230 m rise in 600 m, and at Lanbraehead, 200 m rise in 300 m.

Soils

The soils of the study area have developed since the last glaciation. The major part of the area is covered in glacial debris of varying thicknesses. The derivation of the parent materials is complex but in general they are mainly acid and have weathered little since their deposition.

At present the Macauley Institute has not published a memoir for the Dumfriesshire area but Bown (1972)[1] working to the west of the study area has observed that the Ettrick Association occurs on the greywackes, flagstones and shales of Ordovician and Silurian descent and from the drifts derived from these rocks. As noted previously these rocks cross the entire study area and it is very likely that the same Ettrick Association is dominant in the basin of the Nith. Bown (1972) has grouped the association into 4 series, the freely drained Linhope, the imperfectly drained Dod and Kedslie and the poorly drained Ettrick.

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[1] Bown, C.J. (1972). The Soils of Carrick and the Country around Girvan. Macauley Institute for Soil Science, Aberdeen.

The Linhope series is found on hill tops and steep slopes of southern aspect at about 330 m. It is a brown forest soil of low base status. Its drainage is free having developed from medium texture frost shattered or soliflucted greywackes and shales having a high stone content. The soil has a thin (10 mm) organic horizon. The A and B_2 horizons to 45 cms are dark brown, of low organic matter content and contain roots. The B_3 horizon extends to 70 cms and is a yellowish brown loam. The brown stony loam C horizon which has no roots or organic matter lies above shattered greywacke.

The Dod series develops on medium texture stony tills of moderate slope and south east aspect at about 335 m. It is an imperfectly drained peaty podzol, but is freely drained below the A_2 horizon. This soil is generally topped by more than 5 cm of raw humus. The A_1 horizon, if present, is a sandy loam and contains quartz grains. The A_2 is gleyed but beyond this the soil is freely drained. The vegetation types found on this series are Nardetum, Molinietum and Callunetum.

The Kedslie series is a brown forest soil found on till of fine texture at lower altitudes on moderate slopes of south east aspect. The drainage class is imperfect. The B_2 horizon is often gleyed and the C horizon is always massive.

The Ettrick series develops on low slopes of fine textured tills at about 180 m. The drainage class is poor due to the fine parent material. The Ettrick is a non-calcarious gley. Moder humus is incorporated into the A_1 horizon. The A_2 and the B_2 horizons are highly gleyed. The C horizon is usually mottled.

In the floodplain of the Nith the ground has been almost totally cultivated and the soils found in these areas would be classed as disturbed agricultural profiles.

Vegetation

Using the MacVean and Radcliffe (1962)[1] classification the area would be described as Oak/Birch woodland. However, due to the influence of man through his tree felling, animal grazing and burning, there remains none of this higher main Oak forest region save a few semi-natural Oak woods around Thornhill. The area is now a mosaic of grass and grass-bog, a transition between the dry east and the wet west, it does tend on the whole, however, to be west and have more Molinia, Molinia-Myrica and deep peat communities. The important vegetation types in this southern region as described by MacVean (1964)[2] are sub-alpine Mardus and Juncus squarrosus grassland, species poor Agrostis-Festuca and Molinia grassland and Calluna-Eriophorum. Trichophorum-Eriophorum and Molinia-Myrica bog. The vegetation types can be associated with specific soil series, for instance the Linhope series carries a typical cover of Agrostis-Fescue often invaded by Pteridium.

Land Use

The anthropogenic grassland described above have, for the most part, derived from deciduous forest and scrub by felling, burning and grazing of domestic animals. Final felling of trees took place in the early 19th century when the land use moved exclusively to hill

[1]MacVean, D.N. & Radcliffe, D.A. (1962). Plant Communities of the Scottish Highlands. London, H.M.S.O.

[2]MacVean, D.N. (1964). Regional Patterns of Vegetation in The Vegetation of Scotland. (Ed. J.H. Burnett) Oliver & Boyd, Edinburgh.

sheep grazing, which today has reached an overall intensity of about 0.6 hectares per sheep, although at higher altitudes the grazing rate may drop to 1.4 hectares per sheep. It might be noted, however, that sheep and cattle grazing took place in pastoral settlements in this area as early as the 11th or 12th centuries.

In the study area the sheep are grazed in "hefts" of between 60 and 100 to 120 hectares. The breeds most commonly found are Blackface and Blackface/Cheviot crosses. Hill farms of 400 hectares are common and there are a number over 800 hectares. The semi-natural <u>Agrostis-Fescue</u> grassland is economically the most important form of vegetation utilised by hill sheep.

In recent years increasingly large areas of hill land have been afforested. Both public and private enterprises are involved in this land use which at present is producing large areas of even age monocultures of coniferous forests, with larch-spruce mixtures predominating. Dalmacallam, Kyle and Upper Nithsdale Forest have all been planted by the Forestry Commission in the catchment in the last 25 years. This type of land use, if developed to the point of being a significant proportion of the catchment area, might have important hydrological consequences (see McDonald, 1973).[1]

The valley floor and the lower areas of the study region are devoted almost entirely to dairy and mixed arable enterprises. In this zone the farm size is considerably smaller, the average extent being some 40 hectares. The main crops grown are wheat, barley, potato and various animal feed crops. Livestock products are

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[1]McDonald, A.T. (1973). Some views on the effects of peat drainage. <u>Scott. For. 27 (4)</u>, 315-327.

fattened lambs, beef and dairy cattle and dairy produce. The spread of afforestation noted in the high ground areas has not encompassed the floodplain areas to any great extent, although some "game" planting of deciduous species has taken place. As in other hill sheep areas there is an important interconnection between the land use on the low ground and on the hill, thus any change of land use pattern on the valley floor must influence the utilisation of hill ground.

Stable Basin Characteristics

All of the measures used in this Section are recommended and explained in Sokalov, Snyder and Szesztay (1971).[1] The maps used in the compilation of the majority of these basin statistics were the Ordnance Survey 1 in 10,560 and 1 in 62,500 series. The catchment has a relatively well defined boundary thus little real difficulty was encountered in identifying the limits of the study area. The basin area measured from the upper limit of the floodplain zone below Friars Carse is some 808 km^2. The basin shape as seen in Figure 1.1 is that of an elongated classically "pear" shaped catchment. It has relative boundary length of 1.53 and mean width to length ratio of 0.1747. Basin width across its apparent centre of gravity is 25.6 km and the river length from its centre of gravity to the outlet point is 33 km. This figure is open to limited revision due to (a) the inherently subjective basis of the method in estimating the apparent centre of gravity, and (b) in the difficulty - somewhat

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[1] Sokalov, A., Snyder, F. & Szeztay, K. (1971). Flood studies: an international guide for collection and processing of data. Technical Papers in Hydrology 8, 1-49. Unesco, Paris.

extreme in the case of the Nith - of identifying clearly the outlet point. In essence there are two "outlets" depending upon definition. The first at a point 2 km below Glencaple where the river is approaching 1 km width from bank to bank including flats and where it may be considered estuarine. The second point lies some 8 km to the south, 2 km beyond the Carse Sands and 1 km to the east of Barron Point. Here the river frees itself from the "Nith" mudflats and enters the Solway estuary. The former point has been used to define the outlet of the Nith. The Index of Assymetry for the basin - a - has a value of -0.129, A_i being 352 km^2 and A_r 456 km^2.

The catchment is intensively drained. The drainage density was calculated as 0.846 km per km^2. This value is very dependent upon the map scale used and was measured as 684 km using the O.S. 1 in 250,000 series. Figure 1.1 gives an indication of the drainage intensity and pattern. In general slopes are not slight, the mean basin slope has a value of 0.07 whilst the river slope is 0.7 percent. Areas of flat land and hollows are low reflected in the R_{LS} value for lake and swamp storage of 0.189 percent.

In essence then the catchment delivers its water load down the steep slopes into fairly dense drainage network aided to some extent by artificial drainage both for farm improvement and for forestry. Little delay can be expected as there are no areas in the upper catchment where major surface depression storage occurs as a modifying effect. Storms moving from west to east or to a lesser extent from north to south will concentrate runoff rapidly in the main stream. The catchment is well equipped to generate runoff which could cause flooding, a possibility which is exacerbated at the southern end of the study area by the potential complication caused by spring tides and wind induced sea surges combining to deny the "land" generated flood an outlet to the lower tidal reaches of the river.

Protection Works

The proneness of the River Nith to flooding has induced the construction of a number of small protection schemes along various sections of the Lower Nith Valley. The largest of these works protects the area from Friars Carse in the north to Martington Bridge, on the outskirts of Dumfries in the south. The bulk of these protection levees were introduced in 1946 by DAFS, but there are reports of protection embankments on this part of the floodplain in the 18th century. Although the levees constructed by DAFS are of faced earthbank design there are also extensive concrete floodwalls up to 2 m thick which have been privately erected since the construction of the DAFS works. Protection of farm buildings and associated equipment is afforded by small raised knolls on which these objects are situated.

APPENDIX 2

1. Data input to and output from the physical model.

2. Questionnaire Surveys.

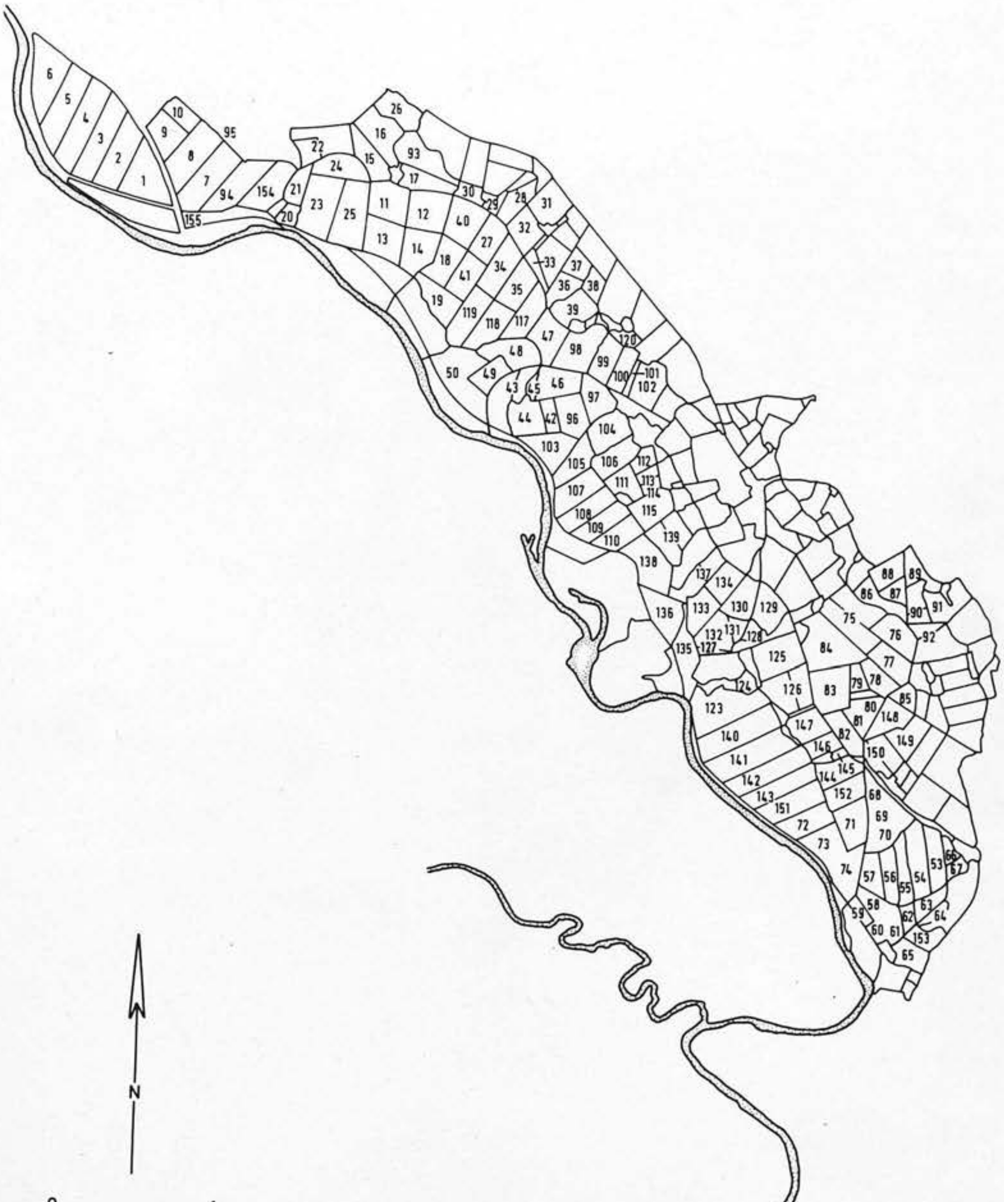

FIGURE A2.1 FIELD NUMBERING ADOPTED IN THE STUDY.

Table A2.1 FIELD AREAS IN THE NITH STUDY

FIELD NUMBER	AREA (ACRES)	AREA (HECTARES)
1	20.44	8.28
2	20.50	8.30
3	30.97	12.54
4	22.70	9.19
5	22.57	9.14
6	20.88	8.45
7	21.40	8.66
8	20.91	8.47
9	12.32	4.99
10	7.19	2.91
11	16.23	6.57
12	17.77	7.19
13	13.15	5.32
14	14.41	5.83
15	8.77	3.55
16	15.78	6.39
17	9.41	3.81
18	12.82	5.19
19	12.09	4.89
20	1.57	0.64
21	7.36	2.98
22	19.31	7.82
23	20.61	8.34
24	12.15	4.92
25	20.61	8.34
26	11.74	4.75

Table A2.1 Continued/

FIELD NUMBER	AREA (ACRES)	AREA (HECTARES)
27	11.87	4.81
28	8.01	3.24
29	1.76	0.71
30	4.47	1.81
31	12.91	5.23
32	10.67	4.32
33	11.02	4.46
34	14.86	6.02
35	12.43	5.03
36	6.76	2.74
37	2.68	1.09
38	5.40	2.19
39	11.37	4.60
40	15.98	6.47
41	11.78	4.77
42	3.52	1.43
43	14.20	5.75
44	7.15	2.89
45	2.31	0.94
46	12.37	5.01
47	13.71	5.55
48	12.23	4.95
49	7.67	3.11
50	27.08	10.96
51	1.00	0.40
52	1.00	0.40

Table A2.1 Continued/

FIELD NUMBER	AREA (ACRES)	AREA (HECTARES)
53	8.53	3.45
54	10.60	4.29
55	7.99	3.23
56	8.75	3.54
57	8.72	3.53
58	5.74	2.32
59	4.04	1.64
60	5.74	2.32
61	5.74	2.32
62	4.65	1.88
63	6.97	2.82
64	3.36	1.36
65	8.54	3.46
66	2.60	1.05
67	3.56	1.44
68	7.72	3.13
69	7.72	3.13
70	7.72	3.13
71	14.70	5.95
72	13.59	5.50
73	9.32	3.77
74	16.76	6.79
75	11.54	4.67
76	11.54	4.67
77	11.54	4.67
78	8.85	3.58

Table A2.1 Continued/

FIELD NUMBER	AREA (ACRES)	AREA (HECTARES)
79	6.60	2.67
80	5.25	2.13
81	5.25	2.13
82	8.88	3.60
83	16.47	6.67
84	24.36	9.86
85	3.31	1.34
86	9.59	3.88
87	5.03	2.04
88	8.46	3.43
89	6.72	2.72
90	5.33	2.16
91	9.00	3.64
92	16.74	6.78
93	15.23	6.17
94	16.90	6.84
95	3.94	1.60
96	7.56	3.06
97	10.95	4.43
98	17.31	7.01
99	10.95	4.43
100	8.13	3.29
101	2.58	1.04
102	13.90	5.63
103	14.31	5.79
104	12.30	4.98

Table A2.1 Continued/

FIELD NUMBER	AREA (ACRES)	AREA (HECTARES)
105	11.59	4.69
106	11.47	4.64
107	14.09	5.70
108	12.55	5.08
109	11.45	4.64
110	11.68	4.73
111	8.58	3.47
112	4.43	1.79
113	2.92	1.18
114	2.48	1.00
115	13.97	5.66
116	1.00	0.40
117	13.43	5.44
118	13.58	5.50
119	14.77	5.98
120	3.64	1.47
121	1.00	0.40
122	1.00	0.40
123	23.58	10.28
124	31.52	12.76
125	18.69	7.57
126	18.25	7.39
127	2.19	0.89
128	2.90	1.17
129	12.75	5.16
130	11.37	4.60

Table A2.1 Continued/

FIELD NUMBER	AREA (ACRES)	AREA (HECTARES)
131	3.88	4.60
132	11.55	4.68
133	11.30	4.57
134	9.85	3.99
135	9.08	3.68
136	15.10	6.11
137	8.10	3.28
138	18.86	7.64
139	14.00	5.67
140	22.93	9.28
141	24.17	9.79
142	18.28	7.40
143	14.93	6.04
144	10.73	4.34
145	1.46	0.59
146	6.26	2.53
147	11.41	4.62
148	10.80	4.37
149	10.14	4.11
150	16.73	6.77
151	16.27	6.59
152	10.17	4.12
153	6.98	2.83
154	16.65	6.74
155	15.45	6.26

Table A2.2 MEAN ELEVATION OF EACH FIELD IN THE NITH FLOODPLAIN

FIELD NUMBER	ELEVATION (METRES)	FIELD NUMBER	ELEVATION (METRES)
1	19.700	27	16.244
2	19.930	28	16.848
3	20.384	29	16.530
4	20.808	30	16.744
5	20.905	31	17.296
6	21.448	32	16.061
7	18.787	33	16.067
8	19.247	34	15.845
9	19.268	35	15.757
10	19.622	36	15.631
11	17.466	37	16.131
12	17.000	38	15.945
13	16.686	39	15.720
14	16.540	40	16.643
15	17.448	41	16.363
16	19.104	42	14.393
17	17.070	43	14.235
18	16.476	44	14.646
19	16.622	45	15.262
20	17.918	46	15.241
21	17.680	47	15.293
22	18.357	48	14.899
23	17.491	49	15.091
24	17.506	50	15.534
25	26.884	51	14.482
26	18.363	52	15.756

Table A2.2 Continued/

FIELD NUMBER	ELEVATION (METRES)	FIELD NUMBER	ELEVATION (METRES)
53	9.662	79	10.582
54	9.744	80	10.037
55	9.527	81	10.460
56	9.537	82	10.637
57	11.402	83	11.101
58	9.957	84	10.405
59	9.881	85	9.796
60	9.375	86	9.686
61	9.491	87	9.826
62	9.396	88	10.226
63	9.527	89	11.037
64	10.198	90	9.924
65	14.927	91	10.058
66	9.835	92	10.640
67	10.088	93	16.887
68	9.817	94	17.259
69	9.854	95	17.271
70	9.622	96	14.421
71	9.814	97	14.613
72	10.198	98	14.848
73	10.732	99	14.750
74	9.905	100	14.628
75	10.116	101	14.235
76	9.899	102	14.890
77	10.037	103	14.466
78	9.866	104	14.229

Table A2.2 Continued/

FIELD NUMBER	ELEVATION (METRES)	FIELD NUMBER	ELEVATION (METRES)
105	13.817	131	11.424
106	14.293	132	11.777
107	14.174	133	12.037
108	13.896	134	12.622
109	13.445	135	11.302
110	13.128	136	13.021
111	13.652	137	11.976
112	13.930	138	12.006
113	13.826	139	11.875
114	13.591	140	11.021
115	13.220	141	10.799
116	14.518	142	13.713
117	15.460	143	10.515
118	15.860	144	10.476
119	16.576	145	10.543
120	14.180	146	10.787
121	16.372	147	11.055
122	17.168	148	9.951
123	11.445	149	9.963
124	11.832	150	9.893
125	12.338	151	10.555
126	11.476	152	10.274
127	10.585	153	9.223
128	11.256	154	17.521
129	12.765	155	17.591
130	13.067		

Table A2.3 COMPUTED FLOOD DEPTHS FOR THE JANUARY 1962 FLOOD

FIELD NUMBER	DEPTH (METRES)	FIELD NUMBER	DEPTH (METRES)
11	0.50	36	2.33
12	0.97	37	1.83
13	1.28	38	2.02
14	1.43	39	2.25
15	0.52	40	1.32
17	0.90	41	1.60
18	1.49	42	0.77
19	1.34	43	0.93
20	0.05	44	0.52
21	0.29	45	0.10
22	0.10	46	0.10
23	0.47	47	2.67
24	0.46	48	0.27
25	1.08	49	0.08
27	1.72	50	2.43
28	1.12	53	1.79
29	1.43	54	1.70
30	1.22	55	1.92
31	0.67	56	1.91
32	1.90	57	0.05
33	1.90	58	1.49
34	2.12	59	1.57
35	2.21	60	2.07

Table A2.3 Continued/

FIELD NUMBER	DEPTH (METRES)	FIELD NUMBER	DEPTH (METRES)
61	1.96	85	1.65
62	2.05	86	1.76
63	1.92	87	1.62
64	1.25	88	1.22
65	0.24	89	0.41
66	1.61	90	1.52
67	1.36	91	1.39
68	1.63	92	0.81
69	1.59	93	1.08
70	1.83	94	0.71
71	1.63	95	0.69
72	1.25	96	0.75
73	0.72	97	0.55
74	1.54	98	0.32
75	1.33	99	0.42
76	1.55	100	0.54
77	1.41	102	0.28
78	1.58	103	0.70
79	0.87	104	0.94
80	1.41	105	1.35
81	0.99	106	0.87
82	0.81	107	0.99
83	0.35	108	1.27
84	1.04	109	1.72

Table A2.3 Continued/

FIELD NUMBER	DEPTH (METRES)	FIELD NUMBER	DEPTH (METRES)
110	2.04	138	3.16
111	1.51	139	3.29
112	1.24	140	0.43
113	1.34	141	0.65
114	1.58	142	0.78
115	1.95	143	0.93
117	2.50	144	0.97
118	2.11	145	0.91
119	1.39	146	0.66
120	0.99	147	0.39
123	0.00	148	1.50
124	0.10	149	1.48
126	0.10	150	1.56
127	4.58	151	0.89
128	3.91	152	1.17
129	2.40	153	2.23
130	2.10	154	0.44
131	3.74	155	0.37
132	3.39		
133	3.13		
134	2.54		
135	3.86		
136	2.15		
137	3.19		

Table A2.4 THE COMPARISON OF THE AREAS FLOODED IN THE JANUARY 1962 FLOOD WITH THE FLOOD AREAS DETERMINED THROUGH THE MODEL

1. FIELD NUMBER	2. FLOOD EVENT CORRECTLY IDENTIFIED IN THE MODEL	3. FLOOD EVENT INCORRECTLY PREDICTED	4. FAILURE TO PREDICT FLOOD
1			X
2			X
3			X
4			X
5			X
6			X
7			X
8			X
9	X		
10	X		
11	X		
12	X		
13	X		
14	X		
15	X		
16	X		
17	X		
18	X		
19	X		
20	X		
21	X		
22	X		
23	X		

Table A2.4 Continued/

1. FIELD NUMBER	2. FLOOD EVENT CORRECTLY IDENTIFIED IN THE MODEL	3. FLOOD EVENT INCORRECTLY PREDICTED	4. FAILURE TO PREDICT FLOOD
24	X		
25	X		
26	X		
27	X		
28		X	
29		X	
30	X		
31		X	
32	X		
33	X		
34	X		
35	X		
36	X		
37		X	
38		X	
39		X	
40	X		
41	X		
42	X		
43	X		
44	X		
45	X		
46	X		
47	X		

<u>Table A2.4</u> Continued/

1. FIELD NUMBER	2. FLOOD EVENT CORRECTLY IDENTIFIED IN THE MODEL	3. FLOOD EVENT INCORRECTLY PREDICTED	4. FAILURE TO PREDICT FLOOD
48	X		
49	X		
50	X		
51	X		
52	X		
53	X		
54	X		
55	X		
56	X		
57	X		
58	X		
59	X		
60	X		
61	X		
62	X		
63	X		
64	X		
65	X		
66	X		
67	X		
68	X		
69	X		
70	X		
71	X		

Table A2.4 Continued/

1. FIELD NUMBER	2. FLOOD EVENT CORRECTLY IDENTIFIED IN THE MODEL	3. FLOOD EVENT INCORRECTLY PREDICTED	4. FAILURE TO PREDICT FLOOD
72	X		
73	X		
74	X		
75		X	
76	X		
77	X		
78	X		
79		X	
80	X		
81	X		
82		X	
83		X	
84		X	
85	X		
86	X		
87	X		
88	X		
89	X		
90	X		
91	X		
92	X		
93	X		
94	X		
95	X		

Table A2.4 Continued/

1. FIELD NUMBER	2. FLOOD EVENT CORRECTLY IDENTIFIED IN THE MODEL	3. FLOOD EVENT INCORRECTLY PREDICTED	4. FAILURE TO PREDICT FLOOD
96	X		
97	X		
98	X		
99	X		
100	X		
101	X		
102		X	
103	X		
104	X		
105	X		
106	X		
107	X		
108	X		
109	X		
110	X		
111	X		
112	X		
113	X		
114	X		
115	X		
116	X		
117	X		
118	X		
119	X		

Table A2.4 Continued/

1. FIELD NUMBER	2. FLOOD EVENT CORRECTLY IDENTIFIED IN THE MODEL	3. FLOOD EVENT INCORRECTLY PREDICTED	4. FAILURE TO PREDICT FLOOD
120		X	
121	X		
122	X		
123	X		
124	X		
125	X		
126	X		
127	X		
128	X		
129	X		
130	X		
131	X		
132	X		
133	X		
134	X		
135	X		
136	X		
137	X		
138	X		
139	X		
140	X		
141	X		
142	X		
143	X		

Table A2.4 Continued/

1. FIELD NUMBER	2. FLOOD EVENT CORRECTLY IDENTIFIED IN THE MODEL	3. FLOOD EVENT INCORRECTLY PREDICTED	4. FAILURE TO PREDICT FLOOD
144	X		
145	X		
146	X		
147	X		
148	X		
149	X		
150	X		
151	X		
152	X		
153	X		
154	X		
155	X		

QUESTIONNAIRE SURVEYS

Methods Employed

Two methods of interview are commonly distinguished, there are structured and unstructured interviews. The former method uses a printed list of questions. The questions are posed in strict order and in the exact form in which they are written. This method ensures high comparability, but lacks flexibility to pursue lines of enquiry which only appear during the survey. The latter method which has been used in this study, presents the sense of the questions but because the interview is unstructured the exact wording may differ slightly in different interviews. In addition, the question sequence may not be exactly the same. This method has flexibility and is believed to inhibit the person being interviewed to a lesser extent that structured interviews. It is this latter advantage which might explain the growing adoption of unstructured interview techniques. Two main types of question were employed: those which asked the person involved to recall a specific event or circumstances, for example a flood depth and those that asked the person to choose from within a set of answers that which they believed to be the most appropriate. No separation of these two types of question was made during the interviews.

Sites

Questionnaire Surveys were carried out in three areas:

(i) In Nithsdale with the farmers in relation (a) to land use, land tenure and their perception of the flood hazard, and (b) to the physical and economic characteristics of past floods. No sampling was carried out in the Nith area. All farmers who had land which was flooded by the 60 year recurrence interval flood of January 1962 were interviewed.

(ii) In the North East of Scotland with the farm managers and other observers of the floods in relation to flood damage and the characteristics of the crop and flood. In addition a general survey was conducted in the area to investigate the ranges in losses suffered and the extent to which individual farms were effected. These were random surveys, the sampling being chosen in the manner described in the text of Chapter V, i.e. random sampling from those farmers known to be inundated - stratified by river.

(iii) In Edinburgh with representatives of Insurance Companies and Brokers, regarding the availability of flood insurance, the overhead costs in relation to the basic premium and the cost of commercial reinsurance.

Results

Those parts of the surveys not utilised at all in this Thesis and those results dealt with specifically in the text are not reported here. The results included here are of parts of the questionnaire surveys which have been briefly introduced in the text to support arguments. Each question has been dealt with individually. The question is posed, the essential results are presented and brief comment is made upon inability and refusals to answer the question.

Do you have another land holding run in conjunction with this farm?

	No	Yes	Total
Replies	3	11	14
Percentage	21	79	100

Refusals = 2

If so is it in a flood prone area?

	No	Yes	Total
Replies	0	11	11
Percentage	0	100	100

Refusals = 0

To what extent do you take the possibility of flooding into account when formulating farm policy?

	Replies	Percentage
Not at all	7	47
To no practical extent	3	20
Borne in mind	2	13
Not a factor of prime importance	2	13
An important factor	1	7
Total	15	100

Refusals = 1

In which of the following four "seasons" do you consider it least likely to flood?

	FMA	MJJ	ASO	NDJ	Total
Replies	4	6	3	1	14
Percentage	29	43	21	7	100

Refusals = 2

How often will floods occur on average now that protection works have been established?

Years	Replies	Percentage
1 - 5	0	0
5 - 10	4	29
10 - 15	6	43
15 - 20	2	14
20 - 25	1	7
25	1	7
Total	14	100

Refusals = 2

How often would floods have occurred on average without protection?

Years	Replies	Percentage
1	1	7
1 - 2	2	14
2 - 3	7	50
3 - 5	3	22
5 - 10	1	7
15	0	0
Total	14	100

From your experience of flooding in this area what proportion of the total losses do you believe stem from damage to items other than the growing crops? For example fencing, draining and feeding systems and field stored machinery and materials.

Years	Replies	Percentage
0 - 10	7	50
10 - 20	5	36
20 - 30	2	14
30 - 40	0	0
40	0	0
Total	14	100

Refusals = 2

Do you provide insurance cover against damage by flooding to growing crops?

	Yes	No	Total
Replies	0	8	8
Percentage	0	100	100

Refusals = 0

Note: Two of the companies concerned were in fact brokers, one of which dealt exclusively with agricultural insurance. It is clear then that the unavailability of insurance covers a much greater field than the eight companies indicated in the summarised results in the Table above.

If you were to provide flood insurance for growing crops, by what percentage would the basic premium have to be raised to cover all overhead expenses with the exception of reinsurance?

	Replies	Percentage
50 - 75	0	0
75 - 100	2	25
100 - 125	4	50
125 - 150	1	12.5
150	1	12.5
Total	8	100

Refusals = 0

Could you delineate on this map the extent of any of the following floods?

	Yes	No	Total
September 1950	0	21	21
January 1962	3	18	21
September 1962	3	18	21
August 1966	5	16	21

Refusals = 1

Note: This survey was largely unsuccessful. Yes replies were given when the farmer could delineate the flooding on his own farm. However, only for the January 1962 flood was the data adequate to define the outline of the whole flood area.

APPENDIX 3

1. Listing of data for study and control sites in the analysis of changes in flood damage potential.

2. Chi square tests.

Table A3.1 LAND USE CHANGES IN THE STUDY AREA (See text for coding)

FIELD NUMBER	BEFORE PROTECTION	AFTER PROTECTION	CHANGE
1	2	4	2R
2	4	2	2L
3	2	4	2R
4	2	2	0
5	2	2	0
6	2	3	1R
8	4	2	2L
9	4	4	0
10	4	4	0
11	2	2	0
12	4	2	2L
13	2	2	0
14	2	2	0
15	4	2	2L
16	2	2	0
17	4	2	2L
18	2	4	2R
19	1	2	1R
23	4	4	0
25	3	4	1R
26	1	2	1R
27	2	4	2R
28	1	2	1R
29	1	1	0
30	4	2	2L
31	2	2	0
32	1	2	1R
33	1	2	1R
34	2	2	0
35	2	2	0
36	1	2	1R
37	1	2	1R
38	1	2	1R

Table A3.1 Continued/

FIELD NUMBER	BEFORE PROTECTION	AFTER PROTECTION	CHANGE
39	1	2	1R
40	2	2	0
41	3	2	1L
42	1	2	1R
43	1	4	3R
44	1	4	3R
45	1	2	1R
46	1	4	3R
47	1	2	1R
49	1	4	3R
53	1	2	1R
54	1	1	0
55	4	4	0
56	4	2	2L
57	1	2	1R
58	1	2	1R
59	1	2	1R
60	1	2	1R
61	1	2	1R
62	1	1	0
63	1	1	0
64	4	2	2L
65	1	2	1R
66	1	1	0
67	1	1	0
68	1	4	3R
69	1	4	3R
70	1	4	3R
71	2	4	2R
72	2	4	2R
73	3	2	1L
74	2	2	0
75	4	2	2L

<u>Table A3.1</u> Continued/

FIELD NUMBER	BEFORE PROTECTION	AFTER PROTECTION	CHANGE
76	3	1	2L
77	1	1	0
79	2	4	2R
81	2	1	1L
82	4	2	2L
83	2	4	2R
84	2	4	2R
86	2	4	2R
87	1	2	1R
88	1	2	1R
89	4	1	3L
90	4	2	2L
91	2	2	0
93	1	2	1R
96	1	2	1R
97	1	2	1R
98	1	2	1R
99	1	2	1R
100	1	2	1R
101	1	2	1R
102	1	2	1R
103	1	2	1R
104	1	2	1R
105	1	2	1R
106	1	4	3R
107	1	2	1R
108	1	2	1R
109	1	2	1R
110	1	2	1R
111	1	2	1R
112	1	2	1R
113	1	2	1R
114	1	4	3R

Table A3.1 Continued/

FIELD NUMBER	BEFORE PROTECTION	AFTER PROTECTION	CHANGE
115	1	4	3R
117	1	2	1R
118	1	2	1R
119	1	2	1R
123	1	4	3R
124	1	1	0
125	2	4	2R
126	3	4	1R
127	4	4	0
129	4	2	2L
130	2	1	1L
132	1	4	3R
133	2	2	0
134	2	2	0
135	1	2	1R
136	1	1	0
138	1	2	1R
139	1	4	3R
140	2	4	2R
141	2	4	2R
142	2	2	0
143	2	2	0
144	2	2	0
145	1	2	1R
146	2	2	0
147	2	4	2R
148	4	4	0
149	4	2	2L
150	4	2	2L
151	4	4	0
152	3	4	1R
153	1	2	1R
156	1	1	0

Table A3.1 Continued/

FIELD NUMBER	BEFORE PROTECTION	AFTER PROTECTION	CHANGE
157	2	2	0
158	2	2	0
159	1	4	3R
160	2	4	2R
161	3	2	1L
162	4	1	3L
163	4	1	3L
164	1	2	1R
165	1	2	1R
166	1	2	1R
168	2	4	2R
169	1	1	0
170	1	2	1R
172	1	2	1R
173	1	2	1R
174	1	2	1R
175	1	2	1R
176	1	2	1R
177	1	2	1R
178	2	2	0
179	3	2	1L
180	1	2	1R
181	1	4	3R
182	1	2	1R
183	1	1	0
184	1	2	1R
185	1	2	1R
186	1	2	1R
187	1	4	3R
188	1	2	1R
189	1	2	1R
190	1	2	1R
192	2	2	0

Table A3.1 Continued/

FIELD NUMBER	BEFORE PROTECTION	AFTER PROTECTION	CHANGE
193	2	2	0
194	1	2	1R
195	2	2	0
196	2	2	0
197	1	2	1R
198	4	2	2L
199	2	2	0
200	1	2	1R
202	2	2	0
203	2	1	1L
204	1	2	1R
205	4	1	3L
206	4	1	3L
207	3	2	1L
208	2	1	1L
209	2	2	0
211	1	1	0
212	1	1	0
213	1	2	1R
215	1	2	1R
219	2	2	0
220	2	2	0
221	2	4	2R
223	3	4	1R
224	4	4	0
227	2	2	0
228	2	4	2R
229	1	2	1R
230	1	2	1R
231	1	3	2R
234	1	1	0
235	1	2	1R
236	1	1	0

Table A3.1 Continued/

FIELD NUMBER	BEFORE PROTECTION	AFTER PROTECTION	CHANGE
237	1	1	0
238	1	1	0
241	1	1	0
242	1	1	0
244	3	2	1L

Table A3.2 LAND USE CHANGES IN THE CONTROL AREA (See text for coding)

FIELD NUMBER	BEFORE TIME OF PROTECTION	AFTER TIME OF PROTECTION	CHANGE
1	1	2	1R
2	1	2	1R
3	3	3	0
4	3	2	1L
5	4	2	2L
6	2	2	0
7	4	2	2L
8	2	2	0
9	2	2	0
10	4	2	2L
11	3	4	1R
12	2	4	2R
13	2	4	2R
14	2	3	1R
15	2	3	1R
16	2	2	0
17	4	2	2L
18	2	4	2R
19	3	4	1R
20	4	1	3L
21	4	1	3L
22	4	2	2L
23	4	2	2L
24	2	4	2R
25	4	4	0
26	2	3	1R
27	4	4	0
28	4	4	0
29	2	4	2R
30	4	4	0
31	2	4	2R
32	2	2	0
33	3	2	1L

Table A3.2 Continued/

FIELD NUMBER	BEFORE TIME OF PROTECTION	AFTER TIME OF PROTECTION	CHANGE
34	4	2	2L
35	2	2	0
36	2	4	2R
37	2	4	2R
38	4	4	0
39	2	2	0
40	2	2	0
41	1	3	2R
42	4	2	2L
43	2	2	0
44	4	2	2L
45	2	2	0
46	2	2	0
47	2	2	0
48	1	2	1R
49	1	2	1R
50	2	2	0
51	4	2	2L
52	4	2	2L
53	3	2	1L
54	3	2	1L
55	1	4	3R
56	1	2	1R
57	2	2	0
58	2	2	0
59	4	2	2L
60	1	2	1R
61	1	2	1R
62	2	2	0
63	3	2	1L
64	2	2	0
65	2	2	0
66	1	2	1R

Table A3.2 Continued/

FIELD NUMBER	BEFORE TIME OF PROTECTION	AFTER TIME OF PROTECTION	CHANGE
67	3	2	1L
68	1	2	1R
69	2	2	0
70	1	2	1R
71	1	2	1R
72	1	2	1R
73	1	2	1R
74	1	2	1R
75	2	2	0
76	2	4	2R
77	1	4	3R
78	2	2	0
79	1	2	1R
80	2	2	0
81	2	2	0
82	2	4	2R
83	2	2	0
84	2	2	0
85	3	2	1L
86	4	2	2L

Table A3.3

Chi square test at the .01 level (1d.f. - $x^2$6.63) of the null hypothesis that the frequency of single and multiple farm holdings in the Nith floodplain does not differ from the frequency of single and multiple holdings found in the South of Scotland.

	Single	Multiple	Total
Nith :	3	11	14
South Scotland:	40,000	10,000	50,000

i	O_i	E_i	$O_i - E_i$	$(O_i - E_i)^2/E_i$
0	11	2.8	8.2	24.01
1	3	11.2	-8.2	24.01
	14	14	0.0	48.02

Calculated Chi square 48.02. Hypothesis rejected at .01 level.

Table A3.4

Chi square test at the .01 level (d.f.2 - $x^2$9.21) of the null hypothesis that the land use changes observed in the study site do not differ from the changes observed in the control site.

	Left Shift	No change	Right Shift	Total
Study Site :	39	51	113	203
Control Site:	21	32	33	86

i	O_i	E_i	$O_i - E_i$	$(O_i - E_i)^2/E_i$
0	31	49.57	-18.57	6.96
1	59	75.53	-16.53	3.62
2	113	77.90	35.10	15.82
	203	203	00.00	26.40

Calculated Chi square 26.40. Hypothesis is rejected at the .01 level.

Reduction of observed data to base 86 yields chi square 10.8.

Table A3.5

Chi square test at the .01 level (d.f.6 - $x^2$16.8) of the null hypothesis that the degree of land use change observed in the study site does not differ from the degree of land use change in the control site.

	Left Shift 3	2	1	No change 0	Right Shift 1	2	3	Total
Study Site :	5	16	10	59	78	19	16	203
Control Site:	2	12	7	32	20	11	2	86

i	O_i	E_i	$O_i - E_i$	$(O_i - E_i)^2 E_i$
0	5	4.72	0.28	0.02
1	16	28.33	-12.33	5.37
2	10	16.52	- 6.52	2.57
3	59	75.53	-16.53	3.62
4	78	47.21	30.79	20.08
5	19	25.97	- 6.97	1.87
6	16	4.72	11.28	26.96
	203	203	00.00	60.49

Calculated x^2 60.49. Hypothesis is rejected at the 0.01 level.

Reduction of observed data to base 86 yields chi square 25.15.

APPENDIX 4

Data and Analysis on Flood Damages

- Basic Data Matrix

- Correlation Matrices

- Correlation Coefficients for Individual Crops

- Partial Correlations

- Full Regression Analysis

- Step up Regression Analysis

- Factor and Principal Component Analysis

Table A4.1 BASIC DATA MATRIX

DAMAGE	LOSS	CROP	AGE	DEPTH	PARTSUB	DURATION	SEDIMENT	VELOCITY
0	2	31	6	50	6	72	1	1
20	5	2	6	50	4	48	1	1
0	5	31	6	16	5	48	1	1
20	4	2	5	16	5	24	1	1
0	1	31	6	16	5	24	1	1
0	0	31	6	90	6	72	2	2
0	0	31	6	45	6	48	1	1
0	0	31	6	60	6	48	2	1
0	0	31	6	45	6	48	1	1
0	0	31	6	45	6	24	1	1
0	0	31	6	45	6	24	1	1
20	0	2	5	45	4	24	1	1
0	0	2	5	30	3	12	1	1
0	0	2	5	30	3	12	1	1
20	0	13	5	30	4	6	1	1
80	8	31	6	120	6	600	3	2
40	18	2	6	120	6	504	3	2
40	6	31	6	90	6	336	3	2
40	170	2	5	90	5	672	3	2
20	5	31	6	120	6	240	2	2
40	6	31	6	190	6	168	3	2
100	8	31	6	120	6	999	3	2
60	3	31	6	130	6	336	3	2
60	3	31	6	130	6	240	3	2
20	1	31	6	90	6	480	3	2

Table A4.1 Continued/

DAMAGE	LOSS	CROP	AGE	DEPTH	PARTSUB	DURATION	SEDIMENT	VELOCITY
40	2	31	6	90	6	240	3	2
20	4	31	6	90	6	168	2	1
20	7	2	5	90	5	168	2	1
40	1	2	5	120	6	240	2	2
80	7	2	5	120	6	336	3	3
80	26	2	5	120	6	240	2	3
100	357	13	5	120	6	480	2	2
100	195	13	5	120	6	480	2	2
20	0	13	5	90	6	12	1	1
0	0	2	5	60	4	12	1	1
20	0	2	5	60	4	168	1	1
80	0	13	5	15	2	168	1	1
80	300	13	5	45	4	168	1	1
80	300	13	5	75	5	72	2	3
40	30	2	6	75	4	96	2	1
20	20	2	6	60	4	72	2	1
20	20	2	6	60	4	96	1	1
20	20	2	6	120	6	72	1	1
20	20	2	6	120	6	72	1	1
20	20	2	6	120	6	80	1	2
20	20	2	6	120	6	80	1	2
40	30	1	5	60	4	168	1	2
60	40	1	5	60	4	168	1	3
0	0	13	5	8	2	12	2	2

Table A4.1 Continued/

DAMAGE	LOSS	CROP	AGE	DEPTH	PARTSUB	DURATION	SEDIMENT	VELOCITY
20	0	2	6	60	4	120	1	1
100	0	1	4	330	6	72	4	3
100	0	1	4	330	6	72	4	3
100	0	1	4	330	6	72	4	3
100	0	1	4	330	6	72	4	3
100	0	1	4	330	6	72	4	3
100	0	1	4	330	6	72	4	3
100	0	1	2	210	6	72	4	3
100	0	1	2	210	6	72	4	3
100	0	1	2	210	6	72	4	3
100	0	1	2	210	6	72	4	2
100	0	1	2	210	6	72	4	2
100	0	1	2	210	6	72	4	2
100	0	1	4	45	6	24	2	3
60	0	1	4	45	6	24	2	2
20	0	1	4	30	6	20	1	1
40	0	1	4	30	6	24	3	1
60	0	1	2	30	6	24	3	3
40	0	1	2	30	6	24	1	2
60	0	1	2	45	6	12	3	1
20	0	1	2	30	6	12	1	1
100	0	2	4	330	6	72	4	3
100	0	2	4	330	6	72	4	3
100	0	2	4	330	6	72	4	3

Table A4.1 Continued/

DAMAGE	LOSS	CROP	AGE	DEPTH	PARTSUB	DURATION	SEDIMENT	VELOCITY
100	0	2	4	330	6	72	4	3
100	0	2	4	330	6	72	4	3
100	0	2	3	210	6	72	4	3
100	0	2	3	210	6	72	4	3
100	0	2	3	210	6	72	4	3
100	0	2	3	210	6	72	4	3
100	0	2	3	210	6	72	4	3
60	0	2	3	30	6	20	2	3
40	0	2	3	45	6	24	1	2
60	0	2	3	45	6	18	3	1
20	0	2	3	30	6	12	1	1
80	0	2	4	45	6	20	2	3
40	0	2	4	75	6	24	1	2
20	0	2	4	30	6	24	1	1
40	0	2	4	30	6	24	3	2
100	0	13	2	330	6	72	4	3
100	0	13	2	330	6	72	4	3
100	0	13	2	330	6	72	4	3
100	0	13	2	330	6	72	4	3
100	0	13	2	330	6	72	4	3
80	0	13	2	60	6	48	2	1
60	0	13	2	30	6	24	2	1
60	120	13	5	60	6	48	1	1
40	60	12	5	60	6	96	1	1
20	1	2	6	75	5	24	2	1

Table A4.1 Continued/

DAMAGE	LOSS	CROP	AGE	DEPTH	PARTSUB	DURATION	SEDIMENT	VELOCITY
40	5	2	6	75	5	240	2	1
80	15	2	6	75	5	24	2	3
20	2	31	6	75	6	24	1	1
20	2	31	6	75	6	24	1	1
20	2	11	5	60	5	24	1	1
100	35	11	5	60	5	480	1	1
20	2	12	5	60	5	24	1	1
100	35	12	5	605	4	801	1	1
80	0	1	3	40	6	12	2	2
0	0	31	6	25	5	12	2	2
40	0	2	4	15	5	6	1	3
40	0	12	4	20	5	12	1	2
80	0	31	3	15	6	8	2	3
40	0	23	4	30	6	12	2	2
40	0	23	4	30	6	12	2	2
0	0	31	6	92	6	48	1	1
80	0	1	3	90	6	48	1	1
80	0	1	3	55	6	36	1	1
100	25	3	6	75	5	96	2	1
80	12	3	6	90	5	48	1	2
100	12	12	5	210	6	48	3	3
40	25	2	6	60	4	48	2	1
60	35	2	6	120	5	48	2	2
80	45	2	6	180	6	48	2	3
80	15	3	6	270	6	84	4	3
80	15	3	6	270	6	84	4	3

Table A4.1 Continued/

DAMAGE	LOSS	CROP	AGE	DEPTH	PARTSUB	DURATION	SEDIMENT	VELOCITY
80	15	3	6	270	6	84	4	3
80	15	3	6	270	6	84	4	3
100	165	13	5	210	6	84	4	3
20	1	12	5	120	6	72	2	1
100	100	22	5	120	6	84	3	1
20	3	3	6	90	5	72	2	1
100	35	3	6	60	4	2	5	3

Table A4.2 ALL DATA PEARSON CORRELATION MATRIX. SIGNIFICANCE LEVELS ARE BRACKETED

	DAMAGE	LOSS	AGE	DEPTH	PARTSUB	DURATION	SEDIMENT	VELOCITY
DAMAGE		0.4210 (.001)	-0.4981 (.001)	0.6373 (.001)	0.2717 (.001)	0.2011 (.001)	0.6825 (.001)	0.6598 (.001)
LOSS			-0.4861 (.001)	-0.0258 (.845)	-0.0288 (.827)	0.1629 (.214)	-0.0047 (.972)	0.1294 (.324)
AGE				NA	NA	NA	NA	NA
DEPTH					0.3417 (.001)	0.1787 (.001)	0.6911 (.001)	0.5708 (.001)
PARTSUB						0.0053 (.951)	0.3792 (.001)	0.3196 (.001)
DURATION							0.0674 (.434)	-0.0089 (.918)
SEDIMENT								0.7328 (.001)
VELOCITY								

Table A4.3 ALL DATA KENDALL CORRELATION MATRIX. SIGNIFICANCE LEVELS ARE BRACKETED.

	DAMAGE	LOSS	AGE	DEPTH	PARTSUB	DURATION	SEDIMENT	VELOCITY
DAMAGE		0.3167 (.017)	-0.4466 (.001)	0.5384 (.001)	0.5243 (.001)	0.1983 (.007)	0.7574 (.001)	0.7154 (.001)
LOSS			-0.0119 (.468)	0.1387 (.177)	-0.0194 (.448)	0.0558 (.355)	0.0156 (.459)	0.2833 (.029)
AGE				NA	NA	NA	NA	NA
DEPTH					0.3379 (.001)	0.4160 (.001)	0.5827 (.001)	0.4814 (.001)
PARTSUB						-0.0339 (.337)	0.4488 (.001)	0.4444 (.001)
DURATION							0.2531 (.002)	0.1747 (.015)
SEDIMENT								0.5858 (.001)
VELOCITY								

Table A4.4 PEARSON CORRELATION COEFFICIENTS BY CROP TYPE BETWEEN LOSS AND THE INDEPENDENT VARIABLES. SIGNIFICANCE LEVELS ARE BRACKETED. XX = CORRELATION CANNOT BE COMPUTED

	AGE	DEPTH	PARTSUB	DURATION	SEDIMENT	VELOCITY
WHEAT	XX	XX	XX	XX	XX	XX
BARLEY	-0.2087 (.364)	0.1364 (.555)	0.0536 (.817)	0.6091 (.003)	0.3836 (.086)	0.1912 (.406)
CEREALS	-0.2522 (.171)	-0.0550 (.769)	0.0298 (.873)	0.5963 (.001)	0.1375 (.461)	0.1360 (.433)
POTATO	XX	-0.2444 (.641)	-0.4682 (.349)	0.3973 (.435)	-0.1773 (.737)	0.1086 (.838)
ROOTS	XX	-0.1973 (.518)	-0.0288 (.926)	0.1474 (.631)	0.1875 (.540)	0.3940 (.193)
PASTURE	XX	0.4584 (.086)	0.1493 (.595)	0.6186 (.014)	0.4316 (.108)	0.4304 (.109)

Table A4.5 KENDALL CORRELATION COEFFICIENTS BY CROP TYPE BETWEEN DAMAGE AND THE INDEPENDENT VARIABLES. SIGNIFICANCE LEVELS ARE BRACKETED

	AGE	DEPTH	PARTSUB	DURATION	SEDIMENT	VELOCITY
WHEAT	-0.0723 (.613)	0.7436 (.001)	0.2958 (.038)	0.4990 (.001)	0.7404 (.001)	0.5850 (.001)
BARLEY	-0.4239 (.001)	0.5120 (.001)	0.5386 (.001)	0.1811 (.073)	0.7798 (.001)	0.7849 (.001)
CEREALS	-0.3485 (.001)	0.5161 (.001)	0.4598 (.001)	0.1508 (.001)	0.7196 (.001)	0.6855 (.001)
POTATO	-0.4431 (.005)	0.6731 (.001)	0.5353 (.001)	0.4677 (.003)	0.5400 (.001)	0.4872 (.002)
ROOTS	-0.3344 (.011)	0.5218 (.001)	0.3501 (.008)	0.5165 (.001)	0.4231 (.001)	0.4086 (.002)
PASTURE	-0.2897 (.042)	0.5197 (.001)	0.3244 (.023)	0.4862 (.001)	0.6450 (.001)	0.6589 (.001)

Table A4.6 KENDALL CORRELATION COEFFICIENTS BY CROP TYPE BETWEEN LOSS AND THE INDEPENDENT VARIABLES. SIGNIFICANCE LEVELS ARE BRACKETED. XX = CORRELATION CANNOT BE COMPUTED

	AGE	DEPTH	PARTSUB	DURATION	SEDIMENT	VELOCITY
WHEAT	XX	XX	XX	XX	XX	XX
BARLEY	0.1598 (.311)	0.2649 (.093)	0.0828 (.600)	0.0001 (.999)	0.1261 (.424)	0.1995 (.206)
CEREALS	-0.0142 (.911)	-0.0388 (.759)	-0.0855 (.499)	0.0348 (.783)	0.0001 (.999)	0.1788 (.158)
POTATO	XX	-0.0714 (.840)	-0.3563 (.315)	0.5000 (.159)	0.0001 (.999)	0.0772 (.828)
ROOTS	XX	-0.0289 (.891)	0.0327 (.876)	0.3538 (.092)	0.1617 (.442)	0.3576 (.089)
PASTURE	XX	0.3957 (.040)	0.1618 (.400)	0.4084 (.034)	0.3682 (.056)	0.3790 (.048)

Table A4.7 ALL DATA PARTIAL CORRELATIONS. SIGNIFICANCE LEVELS ARE BRACKETED

CONTROL VARIABLE ORDER	CONTROL VARIABLES	CORRELATION VARIABLES			
		DEPTH	DURATION	SEDIMENT	VELOCITY
1st	DEPTH			.4158 (.001)	.4441 (.001)
"	DURATION	.6421 (.001)		.6872 (.001)	.6762 (.001)
"	SEDIMENT	.2924 (.001)			.3210 (.001)
"	VELOCITY	.4002 (.001)		.3891 (.001)	
2nd	DEPTH DURATION			.4230 (.001)	.4686 (.001)
"	DEPTH SEDIMENT				.2881 (.001)
"	DEPTH VELOCITY			.2352 (.006)	
"	DURATION SEDIMENT	.2928 (.001)			.3478 (.001)
"	DURATION VELOCITY	.3936 (.001)		.3810 (.001)	
"	SEDIMENT VELOCITY	.2551 (.003)			
3rd	DEPTH DURATION SEDIMENT				.3157 (.001)
"	DEPTH DURATION VELOCITY			.2297 (.008)	
"	DEPTH SEDIMENT VELOCITY				
"	DURATION SEDIMENT VELOCITY	.2521 (.003)			

Table A4.8 PARTIAL CORRELATIONS FOR CEREALS DATA. SIGNIFICANCE LEVELS ARE BRACKETED

CONTROL VARIABLE ORDER	CONTROL VARIABLES	CORRELATION VARIABLES			
		DEPTH	DURATION	SEDIMENT	VELOCITY
1st	DEPTH			.5961 (.001)	.6154 (.001)
"	DURATION	.6823 (.001)		.8044 (.001)	.7793 (.001))
"	SEDIMENT	.2238 (.047)			.5270 (.001)
"	VELOCITY	.4079 (.001)		.5851 (.001)	
2nd	DEPTH DURATION			.6081 (.001)	.6219 (.001)
"	DEPTH SEDIMENT				.5011 (.001)
"	DEPTH VELOCITY			.4721 (.001)	
"	DURATION SEDIMENT	.2135 (.060)			.5356 (.001)
"	DURATION VELOCITY	.4069 (.001)		.5993 (.001)	
"	SEDIMENT VELOCITY	.1225 (.285)			
3rd	DEPTH DURATION SEDIMENT				.5113 (.001)
"	DEPTH DURATION VELOCITY			.4909 (.001)	
"	DEPTH SEDIMENT VELOCITY	.1077 (.351)			
"	DURATION SEDIMENT VELOCITY	.1077 (.351)			

Table A4.9 PARTIAL CORRELATIONS FOR BARLEY DATA. SIGNIFICANCE LEVELS ARE BRACKETED.

CONTROL VARIABLE ORDER	CONTROL VARIABLES	CORRELATION VARIABLES			
		DEPTH	DURATION	SEDIMENT	VELOCITY
1st	DEPTH			.6947 (.001)	.7961 (.001)
"	DURATION	.7439 (.001)		.8793 (.001)	.8781 (.001)
"	SEDIMENT	.2310 (.122)			.7814 (.001)
"	VELOCITY	.5345 (.001)		.7648 (.001)	
2nd	DEPTH DURATION			.7126 (.001)	.7955 (.001)
"	DEPTH SEDIMENT				.7722 (.001)
"	DEPTH VELOCITY			.6555 (.001)	
"	DURATION SEDIMENT	.1759 (.248)			.7907 (.001)
"	DURATION VELOCITY	.5328 (.001)		.7929 (.001)	
"	SEDIMENT VELOCITY	.1360 (.373)			
3rd	DEPTH DURATION SEDIMENT				.7842 (.001)
"	DEPTH DURATION VELOCITY			.6955 (.001)	
"	DEPTH SEDIMENT VELOCITY				
"	DURATION SEDIMENT VELOCITY	.0638 (.681)			

Table A4.10 PARTIAL CORRELATIONS FOR ROOTS DATA. SIGNIFICANCE LEVELS ARE BRACKETED

CONTROL VARIABLE ORDER	CONTROL VARIABLES	CORRELATION VARIABLES			
		DEPTH	DURATION	SEDIMENT	VELOCITY
1st	DEPTH		.3465 (.071)	.0334 (.886)	.0772 (.696)
"	DURATION	.6178 (.001)		.6808 (.001)	.5965 (.001)
"	SEDIMENT	.4254 (.024)	.6952 (.001)		.0106 (.226)
"	VELOCITY	.4799 (.010)	.6436 (.001)	.2363 (.226)	
2nd	DEPTH DURATION			.3860 (.047)	.3136 (.111)
"	DEPTH SEDIMENT		.6055 (.001)		.0852 (.673)
"	DEPTH VELOCITY		.5177 (.006)	-.0492 (.807)	
"	DURATION SEDIMENT	.1445 (.472)			-.0049 (.981)
"	DURATION VELOCITY	.3668 (.060)		.4072 (.035)	
"	SEDIMENT VELOCITY	.4332 (.024)	.6952 (.001)		
3rd	DEPTH DURATION SEDIMENT				.0231 (.911)
"	DEPTH DURATION VELOCITY			.2381 (.241)	
"	DEPTH SEDIMENT VELOCITY		.6032 (.001)		
"	DURATION SEDIMENT VELOCITY	.1462 (.476)			

Table A4.11 PARTIAL CORRELATIONS FOR IMPROVED MEADOWLAND GRAZING DATA. SIGNIFICANCE LEVELS ARE BRACKETED

CONTROL VARIABLE ORDER	CONTROL VARIABLES	DEPTH	DURATION	SEDIMENT	VELOCITY
1st	DEPTH		.6403 (.001)	.5747 (.003)	.6606 (.001)
"	DURATION	.1788 (.402)		.3990 (.053)	.6426 (.001)
"	SEDIMENT	.0437 (.839)	.4860 (.016)		.4009 (.052)
"	VELOCITY	.3738 (.072)	.6737 (.001)	.3749 (.071)	
2nd	DEPTH DURATION			.3635 (.088)	.6316 (.001)
"	DEPTH SEDIMENT		.4851 (.019)		.4332 (.039)
"	DEPTH VELOCITY		.6089 (.002)	.1839 (.401)	
"	DURATION SEDIMENT	-.0279 (.000)			.5520 (.006)
"	DURATION VELOCITY	.0938 (.670)		-.0645 (.770)	
"	SEDIMENT VELOCITY	.1814 (.407)	.6060 (.002)		
3rd	DEPTH DURATION SEDIMENT				.5661 (.006)
"	DEPTH DURATION VELOCITY			-.1369 (.544)	
"	DEPTH SEDIMENT VELOCITY		.6008 (.003)		
"	DURATION SEDIMENT VELOCITY	.1527 (.498)			

Table A4.12 FULL REGRESSION ANALYSIS FOR BARLEY DATA

MULTIPLE r	: .95752	ANALYSIS OF VARIANCE	d.f.	F
r SQUARE	: .91684	REGRESSION	6	73.50165
STANDARD ERROR:	10.6146	RESIDUAL	40	

VARIABLE	B	BETA	STANDARD ERROR B	F
Velocity	19.0440	.50201	2.7410	48.274
Age	.3020	.01009	1.9744	0.023
Depth	.0160	.04348	.0316	0.261
Partsub	.5934	.01810	2.0050	0.088
Duration	-.0288	-.10697	.0144	3.973
Sedload	14.9014	.50901	2.8430	27.474
Constant	-23.2742			

VARIABLE	MULTIPLE r	r SQUARE	r SQUARE CHANGE
Velocity	.87779	.77052	.77052
Age	.88609	.78515	.01463
Depth	.92688	.85910	.07395
Partsub	.92706	.85943	.00033
Duration	.97721	.85972	.00029
Sedload	.95752	.91684	.05712

Table A4.13 FULL REGRESSION ANALYSIS FOR WHEAT DATA

MULTIPLE r :	.86796	ANALYSIS OF VARIANCE	d.f.	F
r SQUARE :	.75336	REGRESSION	6	9.16354
STANDARD ERROR:	15.9848	RESIDUAL	18	

VARIABLE	B	BETA	STANDARD ERROR B	F
Velocity	10.7856	.32134	5.6432	3.653
Age	2.0956	.08025	4.7514	.195
Depth	.0698	-.30754	.0946	.544
Partsub	70.4094	1.39849	31.1244	5.118
Duration	.8532	1.26035	.3926	4.724
Sedload	2.6296	.12477	3.3134	.245
Constant	-410.866			

VARIABLE	MULTIPLE r	r SQUARE	r SQUARE CHANGE
Velocity	.63761	.40654	.40654
Age	.67567	.45655	.05001
Depth	.82117	.67431	.21776
Partsub	.82647	.68304	.00873
Duration	.86603	.75001	.06696
Sedload	.86796	.75336	.00336

Table A4.14 FULL REGRESSION ANALYSIS FOR CEREALS DATA

MULTIPLE r	:	.88030	ANALYSIS OF VARIANCE	d.f.	F
r SQUARE	:	.77493	REGRESSION	6	41.89046
STANDARD ERROR:		16.9860	RESIDUAL	73	

VARIABLE	B	BETA	STANDARD ERROR B	F
Velocity	14.6748	.37981	3.1046	22.343
Age	-3.6126	-.14607	1.7324	4.348
Depth	.0388	.11833	.03180	1.497
Partsub	2.2320	.06003	2.6838	0.692
Duration	-.0192	-.05660	.0198	0.932
Sedload	10.1342	.38032	2.6900	14.193
Constant	5.5300			

VARIABLE	MULTIPLE r	r SQUARE	r SQUARE CHANGE
Velocity	.77517	.60089	.60089
Age	.80972	.65565	.05476
Depth	.85426	.72976	.07411
Partsub	.85426	.73077	.00101
Duration	.85509	.73117	.00040
Sedload	.88030	.77493	.04376

Table A4.15 FULL REGRESSION ANALYSIS FOR POTATO DATA

MULTIPLE r	: .84693	ANALYSIS OF VARIANCE	d.f.	F
r SQUARE	: .71728	REGRESSION	6	5.91996
STANDARD ERROR:	20.3252	RESIDUAL	14	

VARIABLE	B	BETA	STANDARD ERROR B	F
Velocity	-.9810	-.02894	15.3952	.004
Age	-5.6128	-.25432	6.4344	.761
Depth	.1138	.45559	.09080	1.566
Partsub	1.7582	.08848	4.0368	.190
Duration	.1338	.56544	.0380	12.425
Sedload	.6400	.02524	15.3802	.002
Constant	55.762			

VARIABLE	MULTIPLE r	r SQUARE	r SQUARE CHANGE
Velocity	.40235	.16188	.16188
Age	.51294	.26310	.10122
Depth	.66457	.44165	.17855
Partsub	.68185	.46492	.02327
Duration	.84691	.71725	.025233
Sedload	.84693	.71728	.00003

Table A4.16 FULL REGRESSION ANALYSIS FOR ROOT CROP DATA

MULTIPLE r	:	.82450	ANALYSIS OF VARIANCE	d.f.	F
r SQUARE	:	.67980	REGRESSION	6	7.78464
STANDARD ERROR:		21.6554	RESIDUAL	22	

VARIABLE	B	BETA	STANDARD ERROR B	F
Velocity	11.2270	.30197	10.8918	1.062
Age	-8.9348	-.34237	5.0108	3.179
Depth	-.0414	-.17782	.0476	.755
Partsub	4.0668	.17059	3.3498	1.474
Duration	.1378	.76084	.0310	19.778
Sedload	5.444	.19183	10.5914	0.264
Constant	40.1274			

VARIABLE	MULTIPLE r	r SQUARE	r SQUARE CHANGE
Velocity	.42494	.18058	.18058
Age	.48575	.23596	.05538
Depth	.61730	.38105	.14510
Partsub	.62488	.39047	.00942
Duration	.82217	.67596	.28549
Sedload	.82450	.67980	.00385

Table A4.17 FULL REGRESSION ANALYSIS FOR IMPROVED MEADOWLAND GRAZING DATA

MULTIPLE r :	.93495	ANALYSIS OF VARIANCE	d.f.	F
r SQUARE :	.87414	REGRESSION	6	20.83610
STANDARD ERROR:	12.5150	RESIDUAL	18	

VARIABLE	B	BETA	STANDARD ERROR B	F
Velocity	-7.6260	-.14626	11.0302	0.478
Age	-34.4830	-.67723	8.2356	17.531
Depth	.2784	.39190	.1134	6.032
Partsub	-10.9584	-.11897	10.4154	1.107
Duration	.0826	.63079	.0158	27.253
Sedload	4.4802	.12643	7.0618	0.402
Constant	258.2804			

VARIABLE	MULTIPLE r	r SQUARE	r SQUARE CHANGE
Velocity	.71691	.51396	.51396
Age	.71693	.51399	.00003
Depth	.79306	.62895	.11496
Partsub	.79320	.62917	.00023
Duration	.93345	.87133	.24216
Sedload	.93495	.87414	.00281

Table A4.18 DAMAGE REGRESSION FOR CEREALS DATA

		VARIABLES IN THE EQUATION				VARIABLES NOT IN THE EQUATION				
STEP	VARIABLE	B	BETA	STD.ERR.B	F	BETA IN	PARTIAL	TOLERANCE	F	(1) Multiple r (2) r Square (3) STD.ERR. (4) F
1.	SEDIMENT	21.259	.7979	1.819	136.615					.79785 .63656
	(CONSTANT)	8.414								20.882 136.615
	AGE					-.18207	-.28649	.89980	6.885	
	DEPTH					.20414	.21303	.39579	3.661	
	PARTSUB					.22069	.32740	.79991	9.245	
	DURATION					-.10216	-.16864	.99032	2.254	
	VELOCITY					.43299	.52705	.53849	29.615	
2.	SEDIMENT	13.422	.5037	2.120	40.079					.85879
	VELOCITY	16.729	.4330	3.074	29.615					.73751
	(CONSTANT)	-6.887								17.861 108.174
	AGE					-.16823	-.31120	.89819	8.150	
	DEPTH					.07919	.09396	.36948	0.667	
	PARTSUB					.13832	.23330	.74678	4.375	
	DURATION					-.10136	-.19688	.99032	3.065	

Table A4.18 DAMAGE REGRESSION FOR CEREALS DATA

		VARIABLES IN THE EQUATION				VARIABLES NOT IN THE EQUATION				
STEP	VARIABLE	B	BETA	STD.ERR.B	F	BETA IN	PARTIAL	TOLERANCE	F	(1) Multiple r (2) r Square (3) STD.ERR. (4) F
3.	SEDIMENT	12.169	.4567	2.075	34.394					.87346
	VELOCITY	16.375	.4238	2.943	30.952					.76293
	AGE	-4.161	-.1682	1.457	8.150					17.085
	(CONSTANT)	15.169								81.529
	DEPTH					.14429	.17567	.35140	2.388	
	PARTSUB					.07702	.12538	.62817	1.198	
	DURATION					-.06015	-.11771	.90792	1.054	
4.	SEDIMENT	9.605	.36051	2.642	13.217					.87763
	VELOCITY	15.099	.3908	3.031	24.812					.77025
	AGE	-4.667	-.1887	1.409	9.930					16.931
	DEPTH	.047	.1443	.031	2.388					62.861
	(CONSTANT)	20.015								
	PARTSUB					.05508	.08863	.59483	.586	
	DURATION					-.05314	-.10527	.90180	.829	

Table A4.18 DAMAGE REGRESSION FOR CEREALS DATA

		VARIABLES IN THE EQUATION				VARIABLES NOT IN THE EQUATION				
STEP	VARIABLE	B	BETA	STD.ERR.B	F	BETA IN	PARTIAL	TOLERANCE	F	(1) Multiple r (2) r Square (3) STD.ERR. (4) F
5.	SEDIMENT	9.993	.3750	2.679	13.912					.87902
	VELOCITY	15.188	.3931	3.036	25.022					.77280
	AGE	-4.245	-.1716	1.554	7.436					16.951
	DEPTH	.045	.1373	.031	2.142					50.340
	DURATION	-.018	-.0531	.020	0.829					
	(CONSTANT)	18.807								
	PARTSUB					.06003	.09689	.59184	.692	
6.	SEDIMENT	10.134	.3803	2.690	14.193					.88030
	VELOCITY	14.675	.3798	3.105	22.343					.77493
	AGE	-3.613	-.1461	1.732	4.348					16.986
	DEPTH	.0388	.1183	.032	1.497					41.890
	DURATION	-.019	-.0566	.020	.932					
	PARTSUB	2.232	.0600	2.684	.692					
	(CONSTANT)	5.5300								

Table A4.19 DAMAGE REGRESSION FOR WHEAT DATA

		VARIABLES IN THE EQUATION				VARIABLES NOT IN THE EQUATION				
STEP	VARIABLE	B	BETA	STD.ERR.B	F	BETA IN	PARTIAL	TOLERANCE	F	(1) Multiple r (2) r Square (3) STD.ERR. (4) F
1.	DEPTH	.174	.7656	.0304	32.569					
	(CONSTANT)	50.965								
	AGE					-.18919	-.29211	.98675	2.052	.76557
	PARTSUB					.12980	.19642	.94780	.883	.58610
	DURATION					-.05050	.07356	.87809	.120	18.323
	SEDIMENT					.39033	.35391	.34026	3.150	32.569
	VELOCITY					.25635	.30893	.60112	2.321	
2.	DEPTH	.102	.4485	.0500	4.159					
	SEDIMENT	8.227	.3903	4.6350	3.150					
	(CONSTANT)	38.981								
	AGE					-.09452	-.13252	.71172	.375	.79871
	PARTSUB					.04449	.06615	.80042	.092	.63794
	DURATION					.02959	.04370	.78966	.040	17.522
	VELOCITY					.21951	.28006	.58932	1.787	19.382

Table A4.19 DAMAGE REGRESSION FOR WHEAT DATA

	VARIABLES IN THE EQUATION					VARIABLES NOT IN THE EQUATION				
STEP	VARIABLE	B	BETA	STD.ERR.B	F	BETA IN	PARTIAL	TOLERANCE	F	(1) Multiple r (2) r Square (3) STD.ERR. (4) F
3.	DEPTH	.078	.3431	.0522	2.225					.81630
	SEDIMENT	7.365	.3495	4.5996	2.564					.66634
	VELOCITY	7.368	.2195	5.5112	1.787					17.217
	(CONSTANT)	28.537								13.979
	AGE					-.15974	-.22472	.66031	1.064	
	PARTSUB					.14556	.20584	.66719	0.885	
	DURATION					-.04694	-.06710	.68171	.090	
4.	DEPTH	.103	.4555	.0578	3.210					.82655
	SEDIMENT	4.153	.1971	5.549	0.560					.68319
	VELOCITY	8.951	.2667	5.713	2.455					17.193
	AGE	-1.712	-.1597	4.044	1.064					10.782
	(CONSTANT)	43.345								
	PARTSUB					.09829	.13116	.56412	.333	
	DURATION					-.00912	-.01297	.64111	.003	

Table A4.19 DAMAGE REGRESSION FOR WHEAT DATA

	VARIABLES IN THE EQUATION					VARIABLES NOT IN THE EQUATION				
STEP	VARIABLE	B	BETA	STD.ERR.B	F	BETA IN	PARTIAL	TOLERANCE	F	(1) Multiple r (2) r Square (3) STD.ERR. (4) F
5.	DEPTH	.099	.4358	.0592	2.792					.82984
	SEDIMENT	3.387	.1607	5.7980	0.341					.68864
	VELOCITY	10.135	.3020	6.1626	2.705					17.485
	AGE	-3.157	-.1209	4.4738	0.498					8.404
	PARTSUB	4.949	.0981	8.5810	0.333					
	(CONSTANT)	11.330								
	DURATION					1.26035	.45593	.04075	4.724	
6.	DEPTH	-.070	-.3075	.0946	0.544					.86796
	SEDIMENT	2.630	.1248	5.3134	0.245					.75336
	VELOCITY	10.786	.3213	5.6432	3.653					15.988
	AGE	2.096	.0803	4.7514	0.195					9.164
	PARTSUB	70.410	1.3985	31.1244	5.118					
	DURATION	.853	1.2604	.3926	4.724					
	(CONSTANT)	-410.866								

Table A4.20 DAMAGE REGRESSION FOR BARLEY DATA

		VARIABLES IN THE EQUATION				VARIABLES NOT IN THE EQUATION				
STEP	VARIABLE	B	BETA	STD.ERR.B	F	BETA IN	PARTIAL	TOLERANCE	F	(1) Multiple r (2) r Square (3) STD.ERR. (4) F
1.	VELOCITY	33.299	.87779	2.709	151.096					.87779
	(CONSTANT)	-15.257								.77052
	AGE					-.13982	-.25248	.74822	2.996	16.625
	DEPTH					.34479	.55404	.59256	19.489	151.096
	PARTSUB					.06796	.11152	.61793	0.554	
	DURATION					-.02036	.04239	.99491	0.079	
	SEDIMENT					.50301	.76483	.52844	62.015	
2.	VELOCITY	20.170	.5317	2.428	69.012					.95119
	SEDIMENT	14.755	.5040	1.874	62.015					.90476
	(CONSTANT)	-21.506								
	AGE					-.02970	-.08027	.69572	.279	10.831
	DEPTH					.02834	.15272	.36193	1.027	208.989
	PARTSUB					.01577	.03991	.61012	.069	
	DURATION					.10764	.33914	.94541	5.589	

Table A4.20 DAMAGE REGRESSION FOR BARLEY DATA

		VARIABLES IN THE EQUATION				VARIABLES NOT IN THE EQUATION				
STEP	VARIABLE	B	BETA	STD.ERR.B	F	BETA IN	PARTIAL	TOLERANCE	F	(1) Multiple r (2) r Square (3) STD.ERR. (4) F
3.	VELOCITY	19.603	.5167	2.333	71.219					.95693
	SEDIMENT	15.920	.53700	1.829	73.860					.91571
	DURATION	-.029	-.1076	.012	5.589					10.307
	(CONSTANT)	-19.672								155.719
	AGE					.01904	.05086	.60156	.109	
	DEPTH					.05152	.10534	.35244	.471	
	PARTSUB					.02037	.05476	.60941	.126	
4.	VELOCITY	19.269	.5080	2.387	65.151					.95742
	SEDIMENT	14.677	.5013	2.386	37.835					.91665
	DURATION	-.028	-.1025	.013	4.872					10.371
	DEPTH	.019	.0515	.028	0.471					115.471
	(CONSTANT)	-19.142								
	AGE					.00483	.01201	.51568	.006	
	PARTSUB					.01558	.04178	.59932	.072	

Table A4.20 DAMAGE REGRESSION FOR BARLEY DATA

		VARIABLES IN THE EQUATION				VARIABLES NOT IN THE EQUATION				
STEP	VARIABLE	B	BETA	STD.ERR.B	F	BETA IN	PARTIAL	TOLERANCE	F	(1) Multiple r (2) r Square (3) STD.ERR. (4) F
5.	VELOCITY	18.968	.5000	2.663	50.722					
	SEDIMENT	14.679	.5014	2.413	37.007					
	DURATION	-.028	-.1032	.013	4.814					
	DEPTH	.018	.0489	.028	0.408					
	PARTSUB	.5108	.0156	1.908	0.072					
	(CONSTANT)	-21.112								
	AGE					.01009	.02418	.47829	.023	
6.	VELOCITY	19.044	.5020	2.741	48.274					
	SEDIMENT	14.901	.5090	2.843	27.474					
	DURATION	-.029	-.1070	.014	3.973					
	DEPTH	.016	.0435	.032	.261					
	PARTSUB	.593	.0181	2.005	.088					
	AGE	.302	.0101	1.974	.023					
	(CONSTANT)	-23.274								

Table A4.21 DAMAGE REGRESSION FOR ROOTS DATA

	VARIABLES IN THE EQUATION					VARIABLES NOT IN THE EQUATION				
STEP	VARIABLE	B	BETA	STD.ERR.B	F	BETA IN	PARTIAL	TOLERANCE	F	(1) Multiple r (2) r Square (3) STD.ERR. (4) F
1.	DEPTH	.136	.5824	.0364	13.859					
	(CONSTANT)	49.260								.58239
	AGE					-.16751	-.18406	.79789	.912	.33918
	PARTSUB					.15336	.17397	.85041	.811	28.082
	DURATION					.30496	.34652	.85323	3.548	13.859
	SEDIMENT					.21238	.21449	.67404	1.254	
	VELOCITY					.19850	.21665	.78715	1.280	
2.	DEPTH	.109	.4656	.038	8.269					
	DURATION	.055	.3050	.029	3.548					.64694
	(CONSTANT)	44.981								.41853
	AGE					-.46528	-.46221	.57383	6.792	26.844
	PARTSUB					.24811	.28999	.79439	2.295	9.357
	SEDIMENT					.64799	.55977	.43393	11.409	
	VELOCITY					.44194	.45514	.61671	6.532	

Table A4.21 DAMAGE REGRESSION FOR ROOTS DATA

		VARIABLES IN THE EQUATION				VARIABLES NOT IN THE EQUATION				
STEP	VARIABLE	B	BETA	STD.ERR.B	F	BETA IN	PARTIAL	TOLERANCE	F	(1) Multiple r (2) r Square (3) STD.ERR. (4) F
3.	DEPTH	-.008	-.0361	.0470	.032					
	DURATION	.117	.6487	.031	14.473					.77507
	SEDIMENT	18.391	.6480	5.445	11.409					.60073
	(CONSTANT)	14.579								22.684
	AGE					-.30278	-.33910	.50080	3.118	12.538
	PARTSUB					.19961	.27997	.78547	2.041	
	VELOCITY					.00637	.00637	.21306	.001	
4.	DEPTH	-.032	-.1355	.047	.450					
	DURATION	.134	.7380	.031	18.549					.80414
	SEDIMENT	14.865	.5238	5.596	7.056					.64665
	AGE	-7.902	-.3028	4.475	3.118					21.780
	(CONSTANT)	55.866								10.980
	PARTSUB					.15386	.22377	.74744	1.212	
	VELOCITY					.26088	.18195	.17185	.787	

Table A4.21 DAMAGE REGRESSION FOR ROOTS DATA

	VARIABLES IN THE EQUATION					VARIABLES NOT IN THE EQUATION				
STEP	VARIABLE	B	BETA	STD.ERR.B	F	BETA IN	PARTIAL	TOLERANCE	F	(1) Multiple r (2) r Square (3) STD.ERR. (4) F
5.	DEPTH	-.042	-.1791	.048	.764					
	DURATION	.136	.7532	.031	19.367					
	SEDIMENT	14.733	.5191	5.573	6.989					.81507
	AGE	-6.795	-.2604	4.567	2.214					.66434
	PARTSUB	3.668	.1539	3.331	1.212					21.685
	(CONSTANT)	34.407								9.104
	VELOCITY					.30197	.21464	.16958	1.062	
6.	DEPTH	-.041	-.1778	.048	.755					
	DURATION	.138	.7608	.031	19.778					
	SEDIMENT	5.444	.1918	10.581	0.264					.82450
	AGE	-8.935	-.3424	5.011	3.179					.67980
	PARTSUB	4.067	.1076	3.349	1.474					21.655
	VELOCITY	11.227	.3020	10.892	1.062					7.785
	(CONSTANT)	40.127								

Table A4.22 DAMAGE REGRESSION FOR POTATO DATA

	VARIABLES IN THE EQUATION					VARIABLES NOT IN THE EQUATION				
STEP	VARIABLE	B	BETA	STD.ERR.B	F	BETA IN	PARTIAL	TOLERANCE	F	(1) Multiple r (2) r Square (3) STD.ERR. (4) F
1.	DEPTH	.162	.6505	.044	13.934					
	(CONSTANT)	51.530								.65045
	AGE					.02168	.02001	.49164	.007	.42309
	PARTSUB					.23857	.23866	.57736	1.087	24.923
	DURATION					.50546	.66342	.99383	14.150	13.934
	SEDIMENT					-.29198	-.18688	.23635	0.651	
	VELOCITY					-.18915	-.16554	.44189	0.507	
2.	DEPTH	.172	.6902	.034	16.381					
	DURATION	.120	.5055	.032	14.150					.82280
	(CONSTANT)	35.794								.67700
	AGE					-.29138	-.33286	.42148	2.118	19.160
	PARTSUB					.14827	.19626	.56595	0.681	18.864
	SEDIMENT					-.00978	-.00806	.21874	0.001	
	VELOCITY					-.13190	-.15382	.43930	0.412	

Table A4.22 DAMAGE REGRESSION FOR POTATO DATA

		VARIABLES IN THE EQUATION				VARIABLES NOT IN THE EQUATION				
STEP	VARIABLE	B	BETA	STD.ERR.B	F	BETA IN	PARTIAL	TOLERANCE	F	(1) Multiple r (2) r Square (3) STD.ERR. (4) F
3.	DEPTH	.122	.4885	.048	6.592					
	DURATION	.138	.5829	.033	17.134					.84427
	AGE	-6.431	-.2914	4.419	2.118					.71279
	(CONSTANT)	65.462								18.591
	PARTSUB					.09108	.12379	.53055	.249	14.063
	SEDIMENT					-.04441	-.03862	.21717	.024	
	VELOCITY					-.04102	-.04781	.39015	.037	
4.	DEPTH	.112	.4468	.053	4.450					
	DURATION	.134	.5661	.035	14.650					
	AGE	-5.848	-.2650	4.668	1.570					.84687
	PARTSUB	1.810	.0911	3.627	0.249					.71719
	(CONSTANT)	56.272								19.016
	SEDIMENT					-.00775	-.00655	.20234	.001	10.144
	VELOCITY					-.01281	-.01446	.36070	.003	

F LEVELS INSUFFICIENT FOR FURTHER COMPUTATION

Table A4.23 DAMAGE REGRESSION FOR IMPROVED MEADOWLAND GRAZING DATA

		VARIABLES IN THE EQUATION				VARIABLES NOT IN THE EQUATION				
STEP	VARIABLE	B	BETA	STD.ERR.B	F	BETA IN	PARTIAL	TOLERANCE	F	(1) Multiple r (2) r Square (3) STD.ERR. (4) F
1.	DURATION	.097	.7402	.018	27.866					
	(CONSTANT)	7.006								.74016
	AGE					-.50372	-.74069	.97767	26.740	.54783
	DEPTH					.14407	.17882	.69655	.727	20.985
	PARTSUB					.12714	.18365	.94337	.768	27.866
	SEDIMENT					.37462	.39904	.51305	4.167	
	VELOCITY					.48283	.63265	.80105	15.478	
2.	DURATION	.107	.8154	.013	70.072					
	AGE	-25.648	-.5037	4.960	26.740					
	(CONSTANT)	156.090								.89213
	DEPTH					.32414	.57759	.64804	10.513	.79590
	PARTSUB					.06883	.14698	.93078	0.464	14.416
	SEDIMENT					.26122	.40780	.49743	4.189	42.896
	VELOCITY					.19960	.29358	.44154	1.981	

Table A4.23 DAMAGE REGRESSION FOR IMPROVED MEADOWLAND GRAZING

		VARIABLES IN THE EQUATION				VARIABLES NOT IN THE EQUATION				
STEP	VARIABLE	B	BETA	STD.ERR.B	F	BETA IN	PARTIAL	TOLERANCE	F	(1) Multiple r (2) r Square (3) STD.ERR. (4) F
3.	DURATION	.085	.64765	.013	45.094					
	AGE	-29.325	-.57593	4.297	46.583					.92951
	DEPTH	.230	.32414	.071	10.513					.86399
	(CONSTANT)	163.842								12.045
	PARTSUB					-.09687	-.21693	.68207	.988	44.467
	SEDIMENT					.07096	.11071	.33101	.248	
	VELOCITY					.01372	.02167	.33920	.009	
4.	DURATION	.084	.6413	.013	43.991					
	AGE	-30.565	-.6003	4.475	46.644					
	DEPTH	.273	.3842	.083	10.814					.93295
	PARTSUB	-8.923	-.0969	8.979	.988					.87039
	(CONSTANT)	220.468								12.084
	SEDIMENT					.03638	.05602	.30733	.060	33.578
	VELOCITY					-.05855	-.08493	.27274	.138	

Table A4.23 DAMAGE REGRESSION FOR IMPROVED MEADOWLAND GRAZING

		VARIABLES IN THE EQUATION				VARIABLES NOT IN THE EQUATION				
STEP	VARIABLE	B	BETA	STD.ERR.B	F	BETA IN	PARTIAL	TOLERANCE	F	(1) Multiple r (2) r Square (3) STD.ERR. (4) F
5.	DURATION	.086	.6595	.014	35.757					
	AGE	-32.871	-.6456	7.710	18.178					.93345
	DEPTH	.297	.4187	.108	7.648					.87133
	PARTSUB	-10.606	-.1151	10.236	1.074					12.317
	VELOCITY	-3.052	-.0586	8.216	.138					25.732
	(CONSTANT)	246.254								
	SEDIMENT					.12643	.14789	.17605	.402	
6.	DURATION	.083	.6308	.016	27.253					
	AGE	-34.483	-.6772	8.236	17.531					
	DEPTH	.278	.3919	.113	6.032					.93495
	PARTSUB	-10.958	-.1190	10.415	1.107					.87414
	VELOCITY	-7.626	-.1463	11.030	.478					12.515
	SEDIMENT	4.480	.1264	7.062	.402					20.836
	(CONSTANT)	258.280								

	FACTOR 1	FACTOR 2	FACTOR 3
INITIAL FACTOR MATRIX			
AGE	·59484	·51061	-·18886
DEPTH	-·79447	·24928	-·10797
PARTSUB	-·47711	·24919	·72065
DURATION	-·05224	·75653	-·45437
SEDIMENT	-·87001	·15184	·03140
VELOCITY	-·82875	·03290	-·00553
EIGENVALUE	3·55244	1·44042	1·03286
PCT. OF VAR.	44·4	18·0	12·9
CUM. PCT.	44·4	62·4	75·3
ROTATED FACTOR MATRIX			
AGE	-·47021	·65350	·04551
DEPTH	·83094	·09561	·07326
PARTSUB	·39266	-·22499	·77504
DURATION	·24216	·85796	-·02498
SEDIMENT	·86773	-·06862	·15262
VELOCITY	·81434	-·14533	·06054

TABLE A4.24 VARIMAX ROTATED PRINCIPAL COMPONENTS ANALYSIS OF ALL DATA.

	FACTOR 1	FACTOR 2	FACTOR 3
INITIAL FACTOR MATRIX			
AGE	·20292	1·04259	
DEPTH	-·85433	-·09351	
PARTSUB	-·76515	-·11334	
DURATION	-·35138	·68527	
SEDIMENT	-·90228	-·17757	
VELOCITY	-·88754	-·22424	
EIGENVALUE	5·13821	2·21702	
PCT. OF VAR.	64·2	27·7	
CUM. PCT.	64·2	91·9	
ROTATED FACTOR MATRIX			
AGE	-·44591	·96402	
DEPTH	·85196	·11311	
PARTSUB	·77009	·07257	
DURATION	·17766	·74934	
SEDIMENT	·91858	·04292	
VELOCITY	·91541	-·00591	

TABLE A4.25 VARIMAX ROTATED PRINCIPAL COMPONENTS ANALYSIS OF BARLEY DATA.

	FACTOR 1	FACTOR 2	FACTOR 3
INITIAL FACTOR MATRIX			
AGE	-·32896	·77277	-·61715
DEPTH	-·88048	-·09964	·18357
PARTSUB	-·35042	-·91263	-·53312
DURATION	-·52976	·81494	·18511
SEDIMENT	-·83172	-·38614	·23288
VELOCITY	-·80257	·17704	·26106
EIGENVALUE	4·79171	2·35263	1·08365
PCT. OF VAR.	58·9	29·4	13·5
CUM. PCT.	58·9	89·3	102·9
ROTATED FACTOR MATRIX			
AGE	-·04249	1·02365	-·19131
DEPTH	·89366	·13944	·02826
PARTSUB	·31032	-·04235	1·06855
DURATION	·40450	·55795	-·71001
SEDIMENT	·91692	-·08606	·21666
VELOCITY	·79756	·22223	-·24107

TABLE A4.26 VARIMAX ROTATED PRINCIPAL COMPONENTS ANALYSIS OF WHEAT DATA.

	FACTOR 1	FACTOR 2	FACTOR 3
INITIAL FACTOR MATRIX			
AGE	·53056	-·74838	
DEPTH	-·80704	-·33210	
PARTSUB	-·70122	·20061	
DURATION	-·00205	-·47443	
SEDIMENT	-·86839	-·25235	
VELOCITY	-·82669	-·23927	
EIGENVALUE	3·77728	1·68107	
PCT. OF VAR.	47·2	21·0	
CUM. PCT.	47·2	68·2	
ROTATED FACTOR MATRIX			
AGE	-·31328	·86222	
DEPTH	·86620	·10636	
PARTSUB	·62299	-·37926	
DURATION	·12770	·45692	
SEDIMENT	·90421	·01321	
VELOCITY	·86054	·01164	

TABLE A4.27 VARIMAX ROTATED PRINCIPAL COMPONENTS ANALYSIS OF CEREALS DATA.

	FACTOR 1	FACTOR 2	FACTOR 3
INITIAL FACTOR MATRIX			
AGE	·32285	1·00566	·43095
DEPTH	-·94259	-·29067	·02185
PARTSUB	-·76570	-·07313	-·36767
DURATION	-·25914	·82442	-·40966
SEDIMENT	-·90726	-·33490	·30990
VELOCITY	-·82726	-·16902	·49766
EIGENVALUE	4·93033	2·47927	1·08370
PCT. OF VAR.	61·6	31·0	13·5
CUM. PCT.	61·6	92·6	106·2
ROTATED FACTOR MATRIX			
AGE	-·20229	-·29384	1·08353
DEPTH	·80463	·51192	-·25290
PARTSUB	·39017	·73893	-·16903
DURATION	-·21402	·65539	·66279
SEDIMENT	·95802	·26587	-·20694
VELOCITY	·97342	·11400	·00722

TABLE A4.28 VARIMAX ROTATED PRINCIPAL COMPONENTS ANALYSIS OF POTATO DATA.

INITIAL FACTOR MATRIX	FACTOR 1	FACTOR 2	FACTOR 3
AGE	-·18741	1·03663	
DEPTH	-·80064	·25933	
PARTSUB	-·56871	·20297	
DURATION	-·81795	·00800	
SEDIMENT	-·87720	-·18073	
VELOCITY	-·74863	-·57727	
EIGENVALUE	5·10012	1·86872	
PCT. OF VAR.	63·8	23·4	
CUM. PCT.	63·8	87·1	
ROTATED FACTOR MATRIX			
AGE	·73764	-·75207	
DEPTH	·80795	·23550	
PARTSUB	·58446	·15176	
DURATION	·68102	·45311	
SEDIMENT	·62396	·64251	
VELOCITY	·29474	·89823	

TABLE A4.29 VARIMAX ROTATED PRINCIPAL COMPONENTS ANALYSIS OF IMPROVED MEADOWLAND PASTURE DATA.

	FACTOR 1	FACTOR 2	FACTOR 3
INITIAL FACTOR MATRIX			
AGE	·59484	·51061	-·18886
DEPTH	-·79447	·24928	-·10797
PARTSUB	-·47711	·24191	·72065
DURATION	-·05224	·76563	-·45437
SEDIMENT	-·87001	·15184	·03140
VELOCITY	-·82875	·03290	-·00553
EIGENVALUE	3·55244	1·44042	1·03286
PCT. OF VAR.	44·4	18·0	12·9
CUM. PCT.	44·4	62·4	75·3
ROTATED FACTOR MATRIX			
AGE	-·51711	·61374	·07845
DEPTH	·82320	·15800	·04858
PARTSUB	·43542	-·21261	·75545
DURATION	·17459	·87452	-·00978
SEDIMENT	·87521	-·00476	·12225
VELOCITY	·82470	-·08312	·02994

TABLE A4.30 QUARTIMAX ROTATED PRINCIPAL COMPONENTS ANALYSIS OF ALL DATA.

INITIAL FACTOR MATRIX	FACTOR 1	FACTOR 2	FACTOR 3
AGE	•20292	1•04259	
DEPTH	-•85433	-•09351	
PARTSUB	-•76515	-•11334	
DURATION	-•35138	•68527	
SEDIMENT	-•90228	-•17757	
VELOCITY	-•88754	-•22424	
EIGENVALUE	5•13821	2•21702	
PCT. OF VAR.	64•2	27•7	
CUM. PCT.	64•2	91•9	
ROTATED FACTOR MATRIX			
AGE	-•39206	•98715	
DEPTH	•85690	•06595	
PARTSUB	•77292	•02999	
DURATION	•21872	•73840	
SEDIMENT	•91955	-•00781	
VELOCITY	•91369	-•05639	

TABLE A4.31 QUARTIMAX ROTATED PRINCIPAL COMPONENTS ANALYSIS OF BARLEY DATA.

	FACTOR 1	FACTOR 2	FACTOR 3
INITIAL FACTOR MATRIX			
AGE	-·32896	·77277	-·61715
DEPTH	-·88048	-·09964	·18357
PARTSUB	-·35042	-·91263	-·53312
DURATION	-·52976	·81494	·18511
SEDIMENT	-·83972	-·38614	·23288
VELOCITY	-·80257	·17704	·26106
EIGENVALUE	4·79171	2·35263	1·08365
PCT. OF VAR.	59·9	29·4	13·5
CUM. PCT.	59·9	89·3	102·9
ROTATED FACTOR MATRIX			
AGE	·06155	-·21162	1·01867
DEPTH	·90388	.00190	·04332
PARTSUB	·33414	1·06071	-·05601
DURATION	·44146	-·73194	·49842
SEDIMENT	·90827	·19433	-·17993
VELOCITY	·80958	-·26650	·13104

TABLE A4.32 QUARTIMAX ROTATED PRINCIPAL COMPONENTS ANALYSIS OF WHEAT DATA.

	FACTOR 1	FACTOR 2	FACTOR 3
INITIAL FACTOR MATRIX			
AGE	·53056	-·74838	
DEPTH	-·80704	-·33210	
PARTSUB	-·70122	·20061	
DURATION	-·00205	-·47443	
SEDIMENT	-·86839	-·25235	
VELOCITY	-·82669	-·23927	
EIGENVALUE	3·77728	1·68107	
PCT. OF VAR.	47·2	21·0	
CUM. PCT.	47·2	68·2	
ROTATED FACTOR MATRIX			
AGE	-·33775	·85293	
DEPTH	·86281	·13104	
PARTSUB	·63356	-·36133	
DURATION	·11461	·46038	
SEDIMENT	·90347	·03901	
VELOCITY	·85986	·03619	

TABLE A4.33 QUARTIMAX ROTATED PRINCIPAL COMPONENTS ANALYSIS OF CEREALS DATA.

INITIAL FACTOR MATRIX	FACTOR 1	FACTOR 2	FACTOR 3
AGE	·32285	1·00566	·43095
DEPTH	-·94259	-·29067	·02185
PARTSUB	-·76570	-·07313	-·36767
DURATION	-·25914	·82442	-·40966
SEDIMENT	-·90726	-·33490	·30990
VELOCITY	-·82726	-·16902	·49766
EIGENVALUE	4·93033	2·47927	1·08370
PCT. OF VAR.	61·6	31·0	13·5
CUM. PCT.	61·6	92·6	106·2
ROTATED FACTOR MATRIX			
AGE	-·37131	·19514	1·06083
DEPTH	·94241	·14917	-·25112
PARTSUB	·61492	·49173	-·32694
DURATION	-·05010	·88636	·35567
SEDIMENT	1·00647	-·09314	-·09828
VELOCITY	·95599	-·15266	·15287

TABLE A4.34 QUARTIMAX ROTATED PRINCIPAL COMPONENTS ANALYSIS OF POTATO DATA.

	FACTOR 1	FACTOR 2	FACTOR 3
INITIAL FACTOR MATRIX			
AGE	-·18741	1·03663	
DEPTH	-·80064	·25933	
PARTSUB	-·56871	·20297	
DURATION	-·81795	·00800	
SEDIMENT	-·87720	-·18073	
VELOCITY	-·74863	-·57727	
EIGENVALUE	5·10012	1·86872	
PCT. OF VAR.	63·8	23·4	
CUM. PCT.	63·8	87·1	
ROTATED FACTOR MATRIX			
AGE	·19715	1·03489	
DEPTH	·80304	·25179	
PARTSUB	·57059	·19761	
DURATION	·81799	·00031	
SEDIMENT	·87546	-·18897	
VELOCITY	·74316	-·58429	

TABLE A4.35 QUARTIMAX ROTATED PRINCIPAL COMPONENTS ANALYSIS OF IMPROVED MEADOWLAND PASTURE DATA.

	FACTOR 1	FACTOR 2	FACTOR 3
INITIAL FACTOR MATRIX			
AGE	·52608	·37800	·15136
DEPTH	-·74386	·20093	·06374
PARTSUB	-·40616	·18052	-·38756
DURATION	-·05314	·58868	·41254
SEDIMENT	-·85642	·15166	-·10673
VELOCITY	-·77892	·02580	-·06722
EIGENVALUE	3·20560	1·00448	·53700
PCT. OF VAR.	67·5	21·2	11·3
CUM. PCT.	67·5	88·7	100·0
ROTATED FACTOR MATRIX			
AGE	-·44728	·29894	·39132
DEPTH	·74868	-·11006	·15854
PARTSUB	·49459	·27481	-·16618
DURATION	·11252	·10662	·70394
SEDIMENT	·87430	-·05876	-·00192
VELOCITY	·76546	-·15012	-·05864

TABLE A4.36 VARIMAX ROTATED FACTOR ANALYSIS OF ALL DATA.

	FACTOR 1	FACTOR 2	FACTOR 3
INITIAL FACTOR MATRIX			
AGE	•08952	•70021	
DEPTH	−•37689	−•06280	
PARTSUB	−•33755	−•07612	
DURATION	−•15501	•46023	
SEDIMENT	−•39805	−•11926	
VELOCITY	−•39154	−•15060	
EIGENVALUE	5•13821	2•21702	
PCT. OF VAR.	69•9	30•1	
CUM. PCT.	69•9	100•1	
ROTATED FACTOR MATRIX			
AGE	•67960	−•19093	
DEPTH	−•00702	•38203	
PARTSUB	−•02595	•34506	
DURATION	•47795	•08606	
SEDIMENT	−•05978	•41121	
VELOCITY	−•09174	•40936	

TABLE A4.37 VARIMAX ROTATED FACTOR ANALYSIS OF BARLEY DATA.

	FACTOR 1	FACTOR 2	FACTOR 3
INITIAL FACTOR MATRIX			
AGE	-·15028	·50382	-·59285
DEPTH	-·40223	-·06496	·17634
PARTSUB	-·16008	-·59500	-·51213
DURATION	-·24201	·53131	·17783
SEDIMENT	-·37995	-·25175	·22371
VELOCITY	-·36664	·11542	·25078
EIGENVALUE	4·79171	2·35263	1·08365
PCT. OF VAR.	58·2	28·6	13·2
CUM. PCT.	58·2	86·8	100·0
ROTATED FACTOR MATRIX			
AGE	-·02509	·78452	-·10858
DEPTH	-·01444	-·03719	·44217
PARTSUB	·79588	·06941	·06064
DURATION	-·50297	·26742	·21907
SEDIMENT	·10237	-·19113	·45911
VELOCITY	-·20561	·00505	·41028

TABLE A4.38 VARIMAX ROTATED FACTOR ANALYSIS OF WHEAT DATA.

	FACTOR 1	FACTOR 2	FACTOR 3
INITIAL FACTOR MATRIX			
AGE	•59235	-•91070	
DEPTH	-•76406	-•33659	
PARTSUB	-•61258	•12739	
DURATION	•00373	-•24204	
SEDIMENT	-•84705	-•25217	
VELOCITY	-•77638	-•23358	
EIGENVALUE	3•51491	1•44858	
PCT. OF VAR.	70•8	29•2	
CUM. PCT.	70•8	100•0	
ROTATED FACTOR MATRIX			
AGE	-•30541	1•04258	
DEPTH	•82858	•10263	
PARTSUB	•55006	-•29818	
DURATION	•06603	•23288	
SEDIMENT	•88379	-•00209	
VELOCITY	•81075	•00043	

TABLE A4.39 VARIMAX ROTATED FACTOR ANALYSIS OF CEREALS DATA.

	FACTOR 1	FACTOR 2	FACTOR 3
INITIAL FACTOR MATRIX			
AGE	·14540	·63869	·41398
DEPTH	−·42451	−·18460	·02099
PARTSUB	−·34484	−·04645	−·35319
DURATION	−·11671	·52358	−·39352
SEDIMENT	−·40859	−·21269	·29770
VELOCITY	−·37257	−·10734	·47806
EIGENVALUE	4·93033	2·47927	1·08370
PCT. OF VAR.	58·0	29·2	12·8
CUM. PCT.	58·0	87·2	100·0
ROTATED FACTOR MATRIX			
AGE	·77470	·01649	·00105
DEPTH	−·22391	·12878	·38472
PARTSUB	−·30008	·38659	·07947
DURATION	·18714	·59406	−·23386
SEDIMENT	−·09232	−·06397	·53684
VELOCITY	·09914	−·13627	·59201

TABLE A4.40 VARIMAX ROTATED FACTOR ANALYSIS OF POTATO DATA.

	FACTOR 1	FACTOR 2	FACTOR 3
INITIAL FACTOR MATRIX			
AGE	-·08299	·75832	
DEPTH	-·35452	·18971	
PARTSUB	-·25182	·14847	
DURATION	-·36219	·00585	
SEDIMENT	-·38843	-·13221	
VELOCITY	-·33149	-·42229	
EIGENVALUE	5·10012	1·86872	
PCT. OF VAR.	73·2	26·8	
CUM. PCT.	73·2	100·0	
ROTATED FACTOR MATRIX			
AGE	·75911	·07547	
DEPTH	·19321	·35263	
PARTSUB	·15096	·25034	
DURATION	·00944	·36211	
SEDIMENT	-·12835	·38972	
VELOCITY	-·41898	·33566	

TABLE A4.41 VARIMAX ROTATED FACTOR ANALYSIS OF IMPROVED MEADOWLAND PASTURE DATA.

INITIAL FACTOR MATRIX	FACTOR 1	FACTOR 2	FACTOR 3
AGE	·52608	·37800	·15136
DEPTH	-·74386	·20093	·06374
PARTSUB	-·40616	·18052	-·38756
DURATION	-·05314	·58868	·41254
SEDIMENT	-·85642	·15166	-·10673
VELOCITY	-·77892	·02580	-·06722
EIGENVALUE	3·20560	1·00448	0·53700
PCT. OF VAR.	67·5	21·2	11·3
CUM. PCT.	67·5	88·7	100·0
ROTATED FACTOR MATRIX			
AGE	-·49245	·39559	·20871
DEPTH	·75362	·17219	-·01309
PARTSUB	·45357	-·13662	·35123
DURATION	·08305	·71170	·07841
SEDIMENT	·87366	·01842	·06502
VELOCITY	·77998	-·04639	-·03712

TABLE A4.42 QUARTIMAX ROTATED FACTOR ANALYSIS OF ALL DATA.

	FACTOR 1	FACTOR 2	FACTOR 3
INITIAL FACTOR MATRIX			
AGE	·08952	·70021	
DEPTH	-·37689	-·06280	
PARTSUB	-·33755	-·07612	
DURATION	-·15501	·46023	
SEDIMENT	-·39805	-·11926	
VELOCITY	-·39154	-·15060	
EIGENVALUE	5·13821	2·21702	
PCT. OF VAR.	69·9	30·1	
CUM. PCT.	69·9	100·0	
ROTATED FACTOR MATRIX			
AGE	·67960	-·19093	
DEPTH	-·00702	·38203	
PARTSUB	-·02595	·34506	
DURATION	·47795	·08606	
SEDIMENT	-·05978	·41121	
VELOCITY	-·09174	·40936	

TABLE A4.43 QUARTIMAX ROTATED FACTOR ANALYSIS OF BARLEY DATA.

INITIAL FACTOR MATRIX	FACTOR 1	FACTOR 2	FACTOR 3
AGE	-•15028	•50382	-•59285
DEPTH	-•40223	-•06496	•17634
PARTSUB	-•16008	-•59500	-•51213
DURATION	-•24201	•53131	•17783
SEDIMENT	-•37995	-•25175	•22371
VELOCITY	-•36664	•11542	•25078
EIGENVALUE	4•79171	2•35263	1•08365
PCT. OF VAR.	58•2	28•6	13•2
CUM. PCT.	58•2	86•8	100•0
ROTATED FACTOR MATRIX			
AGE	-•02509	•78452	-•10858
DEPTH	-•01444	-•03719	•44217
PARTSUB	•79588	•06941	•06064
DURATION	-•50297	•26742	•21907
SEDIMENT	•10237	-•19113	•45911
VELOCITY	-•20561	•00505	•41028

TABLE A4.44 QUARTIMAX ROTATED FACTOR ANALYSIS OF WHEAT DATA.

	FACTOR 1	FACTOR 2	FACTOR 3
INITIAL FACTOR MATRIX			
AGE	•59235	-•91070	
DEPTH	-•76406	-•33659	
PARTSUB	-•61259	•12739	
DURATION	•00373	-•24204	
SEDIMENT	-•84705	-•25217	
VELOCITY	-•77638	-•23358	
EIGENVALUE	3•51491	1•44858	
PCT. OF VAR.	70•8	29•2	
CUM. PCT.	70•8	100•0	
ROTATED FACTOR MATRIX			
AGE	-•33362	1•03390	
DEPTH	•82549	•12510	
PARTSUB	•55796	-•28313	
DURATION	•05968	•23459	
SEDIMENT	•88352	•02192	
VELOCITY	•81044	•02246	

TABLE A4.45 QUARTIMAX ROTATED FACTOR ANALYSIS OF CEREALS DATA.

	FACTOR 1	FACTOR 2	FACTOR 3
INITIAL FACTOR MATRIX			
AGE	·14540	·63869	·41398
DEPTH	-·42451	-·18460	·02099
PARTSUB	-·34484	-·04645	-·35319
DURATION	-·11671	·52358	-·39352
SEDIMENT	-·40859	-·21269	·29770
VELOCITY	-·37257	-·10734	·47806
EIGENVALUE	4·93033	2·47927	1·08370
PCT. OF VAR.	58·0	29·2	12·8
CUM. PCT.	58·0	87·2	100·0
ROTATED FACTOR MATRIX			
AGE	·77470	·01649	·00105
DEPTH	-·22391	·12878	·38472
PARTSUB	-·30008	·38659	·07947
DURATION	·18714	·59406	-·23386
SEDIMENT	-·09232	-·06397	·53684
VELOCITY	·09914	-·13627	·59201

TABLE A4.46 QUARTIMAX ROTATED FACTOR ANALYSIS OF POTATO DATA.

	FACTOR 1	FACTOR 2	FACTOR 3
INITIAL FACTOR MATRIX			
AGE	-·08299	·75832	
DEPTH	-·35452	·18971	
PARTSUB	-·25182	·14847	
DURATION	-·36219	·00585	
SEDIMENT	-·38843	-·13221	
VELOCITY	-·33149	-·42229	
EIGENVALUE	5·10012	1·86872	
PCT. OF VAR.	73·2	26·8	
CUM. PCT.	73·2	100·0	
ROTATED FACTOR MATRIX			
AGE	·75911	·07547	
DEPTH	·19321	·35263	
PARTSUB	·15096	·25034	
DURATION	·00944	·36211	
SEDIMENT	-·12835	·38972	
VELOCITY	-·41898	·33566	

TABLE A4.47 QUARTIMAX ROTATED FACTOR ANALYSIS OF IMPROVED MEADOWLAND PASTURE DATA.